

NASA
AERONAUTICS

RESEARCH AND TECHNOLOGY

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Program Highlights





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FORWARD



The NASA Lewis Research Center and the NASA/Industry Advanced Turboprop Team were awarded the 1987 Collier Trophy for developing advanced turboprop propulsion technology for new fuel-efficient subsonic aircraft propulsion systems. The trophy is awarded annually for the greatest achievement in aeronautics or astronautics in America.

Aviation in the United States occupies a unique position with its contribution to trade, its coupling with national security and its symbolism of American technological might. Aviation also constitutes a vital domestic and international transportation infrastructure for world commerce. Since the beginning of manned flight, the United States has held a position as a world leader in aviation. This world leadership is founded on a strong national research and technology base and the innovative application of advanced technologies to new concepts and missions.

NASA, and its predecessor, the National Advisory Committee on Aeronautics (NACA), has made contributions over the past 74 years that have been a major factor in establishing and maintaining United States preeminence in aviation. NASA is committed to continuing an assertive, leadership role in developing the knowledge base in emerging areas from which important new advances and breakthroughs in U.S. aeronautics capabilities can flow.

The National Aeronautical R&D Goals, established in 1985, outline opportunities for significant advances in technology that will reshape civil and military aviation by the turn of the century. The sequel report, *National Aeronautical R&D Goals: Agenda for Achievement*, released by the President's Science Advisor in 1987, presents a National strategy and eight concrete actions for preserving America's aeronautical leadership and achieving the National Goals. In addition, the U.S. Senate directed NASA to prepare a multi-year *Civil Aeronautics Technology Development and Validation Plan* that would help retain U.S. leadership in aeronautics research and technology, and enable the U.S. to compete in

the international marketplace for future civil aircraft. This plan was prepared in cooperation with private industry and submitted to the Congress in March 1988. The above documents provide a sound roadmap for addressing the exciting future in aeronautics. The possibilities are as great now, if not greater, than at any time in the history of aviation.

This Report on the NASA Aeronautics Research and Technology Program features recent technical accomplishments and research highlights and offers a glimpse of the exciting possibilities for future research as we focus our program in new directions.

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Single-Rotation Advanced
Turboprop on Gulfstream II
Aircraft

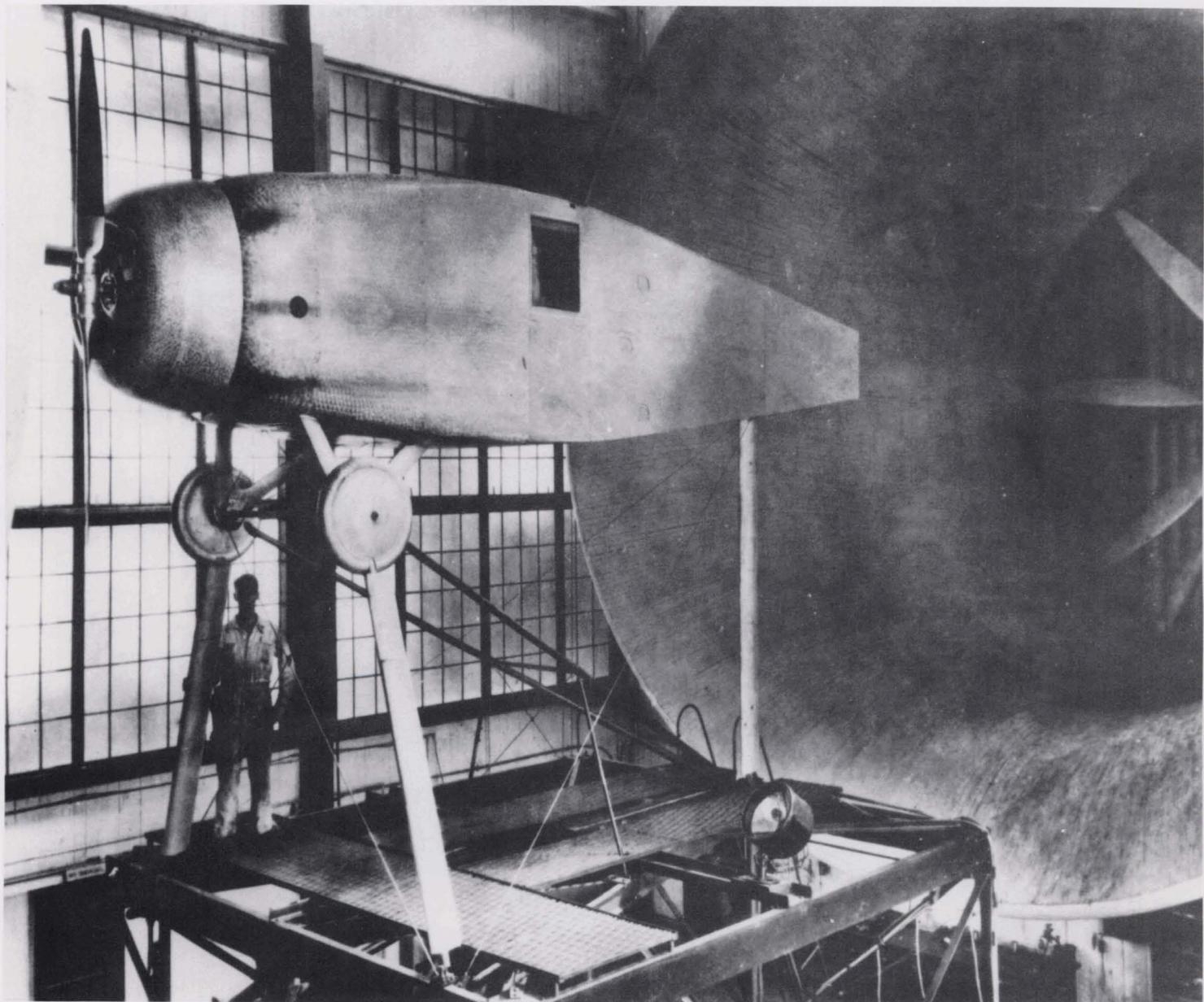
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CONTENTS

FOREWORD	1
INTRODUCTION	5
VEHICLE TECHNOLOGY	11
Subsonic	11
Rotorcraft	13
Supersonic	16
Hypersonic Technology	18
High Performance	20
DISCIPLINE RESEARCH	29
Aerodynamics	29
Propulsion	34
Materials and Structures	37
Information Sciences and	
Human Factors	40
Flight Systems/Safety	43
ORGANIZATION AND INSTALLATIONS	47
SUPPORTIVE RESOURCES	52



In 1929 the Collier Trophy was awarded to Langley Research Center for the development of the NACA cowling for radial air cooled engines. Testing of the NACA cowling at Langley's propeller research tunnel is shown here.

INTRODUCTION

For the greater part of this century, NASA and its predecessor, NACA, have pioneered advanced technology for superior U.S. aircraft. This technological superiority in aeronautics has been attained through independent, long-term, fundamental research. The products of this research have significantly benefited the nation. In addition to making a positive contribution to the trade balance and a secure national defense, American aeronautics is a symbol of this country's technological strength.

While the U.S. has enjoyed pre-eminence in aeronautical technology since WWII, the margin of that advantage has narrowed dramatically in recent years. In a growing number of aircraft related areas, foreign technical capabilities are now comparable, if not superior, to those of the U.S. In addition, there are now disturbing signs that the entire U.S. aviation system is under strain. Falling behind in aeronautical technologies has obvious negative implications relative to the security of the nation.

For the U.S. to retain world leadership in aviation into the next century, the nation must aggressively pursue those technological opportunities which promise dramatic advances in aircraft performance and capability. NASA, with the technical expertise of its cadre of internationally acclaimed scientists and engineers and its unique national aeronautical facilities, will have a pivotal role in developing these emerging technologies.

A number of comprehensive studies in recent years have endorsed the need for a dynamic and positive thrust in aeronautics, and identified conceptual vehicles which serve to focus technology development. In 1982, the Office of Science and Technology Policy (OSTP) chaired a multi-agency study group whose detailed review of U.S. aeronautical R&T policies reiterated the importance of aeronautics to the nation. This report strongly emphasized the necessity for a research and technology base to support the development of superior U.S. aircraft, and reconfirmed the roles of government agencies in aeronautics.

The Aeronautics and Space Engineering Board of the National Research Council conducted a workshop in 1984 that projected the state of knowledge and capability in aeronautical technology areas through the year 2000. This activity also provided a view of vehicle concepts and technology applications into the next century based upon expected future technology and system advances.

In 1985, the OSTP established the National Aeronautical R&D Goals which outlined numerous opportunities for dramatic advances in technology that could reshape civil and military aviation by the beginning of the next century. The U.S. Air Force's Forecast II Study, released in 1986, expanded on the importance of pursuing technologies that could dramatically increase current military aircraft capability. The OSTP Agenda for Achievement, released in 1987, presented a national strategy and eight concrete actions to preserve U.S. leadership. The Aerospace Industries Association (AIA) established eight key technologies for the 1990's which included initiatives in support

of aeronautics research. The AIA has been working closely with industry and government to assure that these initiatives are integrated into future aeronautical R&T program plans. The Civil Aeronautics Technology Development and Validation Plan was developed by NASA and industry, at the request of Congress, to outline major technology needs that would ensure U.S. competitiveness in future international aeronautical markets.

These recent efforts have provided a vision of new generations of advanced civil and military aircraft that could supersede all current aircraft by the turn of the century. NASA's Aeronautics Research and Technology Program is focused on those technologies that will make these future vehicles possible. Potential vehicle applications are described below and the key, or enabling, technologies are identified. In addition to specific vehicle technologies, strong emphasis is also being placed on disciplinary research that addresses major technological opportunities which are broadly applicable to all classes of aircraft, and will establish the technology base for new systems and aircraft not yet defined.

PROGRAM GOALS

In recognition of the serious challenge to America's world leadership in aviation, NASA has maintained a strong commitment to aeronautics research and technology. NASA's technology development activities date back to the founding of NACA in 1915. To ensure the continuation of the highly successful partnership that has evolved among industry, universities, Department of Defense (DoD), and NASA, a comprehensive set of program goals has been established to guide our research and technology development.

- ▼ The first goal of the program is to conduct effective and productive fundamental and systems-oriented aeronautical research to develop and validate technologies that contribute materially to the enduring preeminence of U.S. civil and military aviation.
- ▼ The second goal is to ensure the timely and efficient transition of research results to the U.S. aerospace community through reports, conferences, workshops, and active participation of industry in contractual and cooperative programs.
- ▼ The third goal is to maintain the excellence of NASA's Aeronautical Research Centers by repairing and replacing aging facilities, as well as developing additions and improvements; advancing scientific and engineering computational capabilities; and enhancing staff competence through the selection of highly qualified personnel.
- ▼ The fourth goal is to provide technical expertise and facility support to U.S. industry, the DoD, the Federal Aviation Administration (FAA), and other government agencies involved in major aeronautical programs.

▼ The fifth goal is to ensure strong involvement of universities in NASA's program to broaden the base of technical expertise and innovation, and to foster the education of future aeronautical scientists and engineers.

PROGRAM OBJECTIVES

Vehicle Class Objectives

As mentioned above, NASA conducts a vigorous advanced research and technology development program across a wide range of relevant aeronautical disciplines. To help focus and integrate these activities in response to the National Aeronautical R&D Goals the program addresses five "vehicle-class" objectives. The objectives of the "vehicle-class" programs are to develop and validate the technologies required to enable U.S. industry to design and build these types of vehicles for specific applications. Each of these five vehicle classes is described in more detail below. The brief descriptions include some background on the potential benefits of each vehicle class and the technology challenges to be addressed in making these vehicles possible. These challenges guide the development of OAST's long-range aeronautical program plan:

▼ *Transcentury Subsonic Transport Technology*

The past fifteen years have seen a gradual evolutionary advancement in subsonic aircraft technology. Today, the acceleration of subsonic transport aircraft technology development, in close coordination with the manufacturers, airlines, and the FAA, is essential to the timely introduction of new technology to ensure that the United States retains its leadership role in the world marketplace.

NASA's efforts in the subsonic transport area are focused on both the technology required to develop an entirely new generation of fuel efficient, affordable aircraft, and on the technology required to improve the safety and productivity of the National Airspace System.

Key technology challenges involve the reduction of fuel consumption with advanced turboprop and ultra-high-bypass ratio propulsion systems; reduction of viscous drag by means of laminar flow and turbulence control; reduction of structural weight with advanced composite materials and concepts; and the development of fully integrated flight control and operating systems that interface with a flexible and modernized National Airspace System.

▼ *Advanced Rotorcraft Technology*
Combining the vertical take-off and landing capability of the conventional helicopter with the high speed capability of fixed wing aircraft will make a major contribution to air travel for both the civil and military sectors. Civil applications of these vehicles, for example the tiltrotor, will permit operation in the vertical or short take-off mode with significantly improved economy, productivity, and maintainability. Advanced aircraft of this type will provide improved inter-city and inter-region transportation, thereby reducing congestion in U.S. airports without requiring major investments in new runways.

NASA's objective in this area is to provide the validated technology for revolutionary new rotorcraft with high speed capabilities for both civil and military applications and the development of quiet, jet smooth, highly automated rotorcraft.

F-18 High-Alpha Research Vehicle (HARV)



Technological challenges include reducing wing download in hover operations; reducing cruise drag in high-speed configurations; development of convertible propulsion systems for both efficient cruise and takeoff operations; reducing external noise and airframe vibrations through validated prediction and design methods; reducing crew workload in performing complex piloting tasks through cockpit automation and emerging concepts in man-machine interfaces; and integrating new technologies in materials, controls, and aerodynamics into innovative configurations which combine the vertical lift utility of the rotor with the high speed capability of a fixed wing.

▼ Long-Range Supersonic Cruise Vehicle Technology

United States relations and alliances in the Pacific have major implications for the future. U.S. trade and communication with the Pacific community has increased dramatically and long-haul transpacific travel is currently the fastest growing air travel market. Because of this rapid growth and the extremely long flight times with subsonic aircraft, there is an increasing need for future high-speed aircraft to provide more effective transpacific airline service.

Studies have indicated that future high-speed transport aircraft can be developed that will be economically competitive with long-haul subsonic aircraft. However, current environmental concerns about atmospheric impact, airport noise, and sonic

boom present powerful deterrents to private sector initiative. NASA's high-speed research efforts will explore approaches to resolve these environmental issues and develop the basis for evaluating technology advances that can provide the necessary environmental compatibility.

The atmospheric impact research includes long-term atmospheric chemistry assessments and low emission combustor research. The airport noise reduction research includes investigation into alternative engine cycles and jet noise suppression technology for meeting FAR 36-Stage III noise levels, the same levels achieved by the quietest subsonic aircraft. The

sonic boom reduction research includes the analysis and testing of low sonic boom design options, as well as the evaluation of human response characteristics to define sonic boom acceptability criteria.

Resolution of these critical environmental issues will place the U.S. in a position to make informed decisions on the development of high-speed civil transport aircraft. Foreign development of an advanced technology high-speed transport aircraft poses a severe threat to U.S. aeronautics leadership and could seriously undermine our position as the world's supplier of large, long-range, subsonic transport aircraft.

▼ *Hypersonic Cruise/Transatmospheric Vehicle Technology*
This merging of aeronautics and space technologies provides the potential for an entirely new class of flight vehicles for the next century, ranging from hypersonic aircraft to a single-stage-to-orbit space transportation system. These vehicles would have the ability to take off from and land on conventional runways, sustain hypersonic cruise flight (greater than five times the speed of sound) in the atmosphere, or accelerate into space. The transatmospheric capability made possible by this technology will greatly enhance the operational potential of both civil and military aircraft.

Key to these missions is the development of air-breathing propulsion system technology, providing horizontal take-off, acceleration through the transonic and supersonic speed

range, and sustained operation at hypersonic speeds. Other crucial technology challenges include the development of new high-temperature materials, actively cooled thermal structures for peak and sustained heat loads, revolutionary concepts for highly integrated airframe and propulsion systems, and advanced computational methods to address complex flows, structures, and integration phenomena associated with very high speed vehicles.

▼ *High Performance Aircraft Technology*

NASA's high performance aircraft research program is structured to develop and mature technologies that have important, long-term, military applications. Specific technology programs are carefully selected to demonstrate a significant improvement in performance or to show a new capability that potentially has high military payoff. The methodologies developed in this program also have important applications to a wide range of aeronautical technologies.

NASA's objective in this area is aimed at developing the technology options which would enable a revolutionary new generation of fighter aircraft with unprecedented maneuverability and agility, sustained supersonic cruise, and short take-off/vertical landing (STOVL) capability.

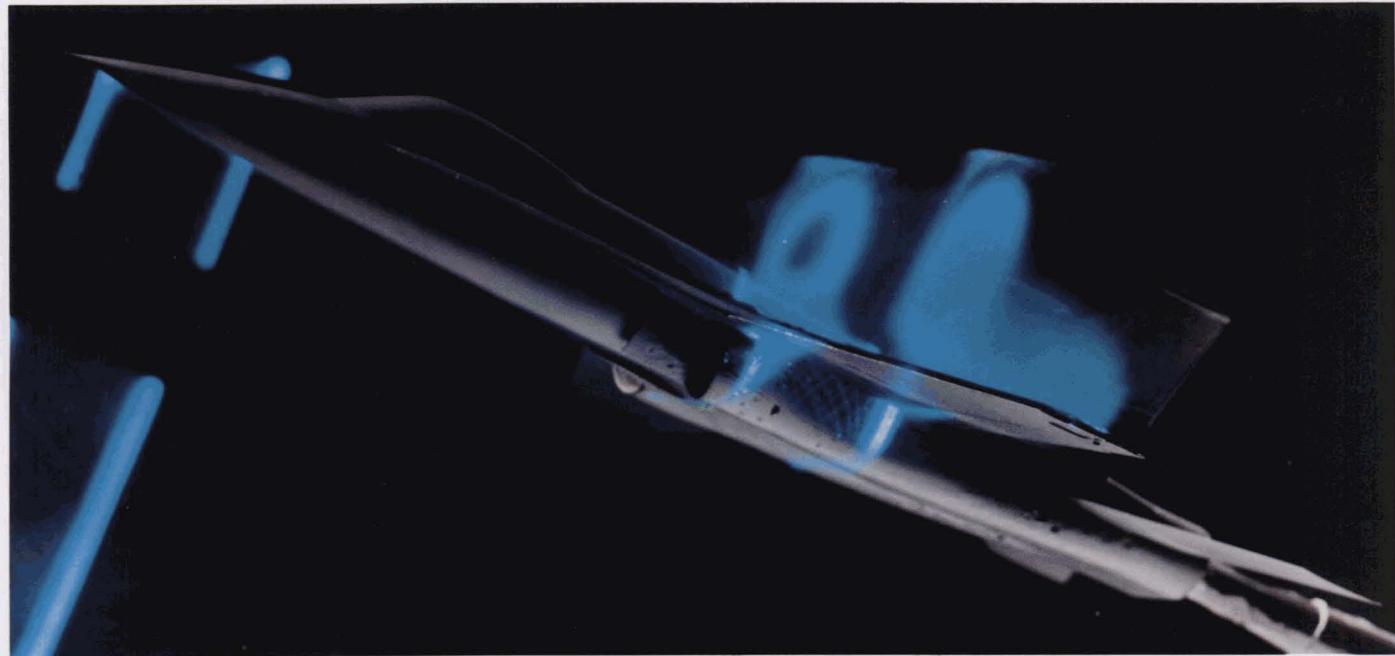
Key technology challenges include achieving effective post-stall flight at angles-of-attack above 60 degrees, increasing propulsion system thrust-to-weight ratios, and developing a short take-off/vertical landing capability within an efficient supersonic cruise vehicle.

Disciplinary Research Objectives

In addition to the vehicle-focused technology efforts, a large portion of NASA's aeronautical research and technology development program consists of disciplinary research that has broad application to the safety, efficiency, and performance of a wide range of aircraft types. Objectives for this research include:

- ▼ develop and validate computational methods for the analysis and prediction of complex external and internal flows, structural mechanics, control theoretics and their interactions to enable confident, practical application of these methodologies to aircraft and engine design;
- ▼ provide design and validation methods for highly reliable, integrated, and interactive control of aerodynamics, structures, and propulsion systems for optimum flight configurations;
- ▼ develop technology for human error tolerant, computer-aided piloting systems and for wind shear modeling and detection;
- ▼ develop methodologies to design intelligent automated systems to enhance crew performance and extend vehicle capability;
- ▼ develop design methodologies and life prediction modeling techniques for advanced high temperature materials such as ceramics, ceramic composites, carbon and metal matrix composites for use in light-weight airframes and high-performance turbine engines; and
- ▼ develop a solid research base to enable the development of new innovative concepts.

Laser Visualization of High Angle-of-Attack Vortex Flow on Wind Tunnel Model



Facility Objectives

Many of NASA's aeronautical research facilities—including wind tunnels, simulators, and advanced computing facilities—are unique, national assets. In addition to supporting the work of NASA, these facilities support research and development work being undertaken by the aerospace industry and other Government agencies, including the FAA, the DoD and the Department of Energy (DOE).

To continue meeting its obligations in this area, NASA's objective is to enhance its aeronautical facility capability by improving the productivity of existing major facilities and extending that capability in critical new technology areas.

SUMMARY

The long-term focus of the NASA Aeronautics Research and Technology Program is intended to provide documented results of advanced aeronautical research well in advance of specific applications and to provide long-term, independent research and technology which is not driven by the development and operational pressures often encountered by the DoD and industry. Fundamental research in the traditional aeronautical disciplines is emphasized in addition to research directed at interaction among disciplines, components, and subsystems. Ongoing and planned research will provide the technological foundation for maintaining world leadership in aeronautics for the United States.

This Report focuses on key technological accomplishments of the NASA Aeronautics Research and Technology Program. The Report is divided into two principal sections—

vehicle technology and disciplinary research. The vehicle technology section highlights activities that are focused on, or clearly applicable to, a particular class of vehicles. Frequently, this research involves the testing of innovative systems in a realistic environment. The disciplinary research section highlights activities in the traditional areas of aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems and safety. This research is aimed at establishing and maintaining a solid foundation of technology, embracing all of the relevant disciplines to provide a wellspring of ideas, concepts and emerging technologies in aeronautics.

Brief descriptions of NASA's organizational structure, wind tunnel revitalization program, university program, and the Aeronautics Advisory Committee are presented in the concluding section of the report.

VEHICLE TECHNOLOGY





SUBSONIC

ASA works closely with aircraft manufacturers, airlines, and the Federal Aviation Administration to advance the technology for subsonic transport aircraft. This close relationship is essential to the timely introduction of new technology to assure the United States retains its preeminent position in this important world market. The research activities in the subsonic program are coupled directly to technology application programs in industry. In this way the timely transfer of research results in the availability of new and enhanced aircraft developments to industry that are in keeping with current aeronautical research and technology policy.

A major goal of the subsonic transport program is to establish the technology that will enable the doubling of fuel efficiency of today's best subsonic transport aircraft, while substantially increasing their productivity and affordability.

In 1987, a NASA/industry team was awarded the Collier Trophy for accomplishments in the Advanced Turboprop Program. This award is made by the National Aeronautics Association for outstanding achievement in Aeronautics and Astronautics.

The Award cited the NASA/Industry Advanced Turboprop Team for the conception, development, and flight verification of advanced turboprop propulsion technology applicable to several new aircraft propulsion systems. This technology base will provide for the future commercial development of advanced turboprop propulsion systems that offer

**Propfan Test Assessment on
Gulfstream II Aircraft**

dramatic reductions in fuel consumption and operating costs. These developments are expected to engender a new generation of subsonic transport aircraft for both civil and military uses.

The initiative for advanced turboprop systems was generated in the mid-1970's in response to rapidly increasing fuel prices resulting from the initial OPEC oil embargo. Advanced propeller designs involving thin, highly swept and twisted blades emerged from cooperative research at the NASA Lewis Research Center and Hamilton Standard. The feasibility of achieving major improvements in aerodynamic propulsive efficiency with these unique propellers operating at high subsonic speeds (Mach 0.8) was subsequently demonstrated in wind tunnel tests.

This led to a major NASA/industry/university program to develop the related aerodynamic, structural, mechanical, and acoustics technologies required for these new turboprop propulsion systems and to verify the potential performance improvements of these systems in both ground and flight tests. The technical expertise of NASA's three aeronautical research centers, Ames, Langley, and Lewis, and more than 40 industry contract and university grant efforts were successfully employed in this program. The contracts and grants involved a broad cross section of the U. S. aeronautics community. This entire program was managed and integrated by NASA Lewis personnel.

The program reached fruition in 1987 with successful verification of technology readiness in three series of flight tests:

▼ General Electric/Boeing flight tests of the General Electric gearless counterrotating Unducted Fan (UDF) on a Boeing B-727 aircraft;



Collier Trophy

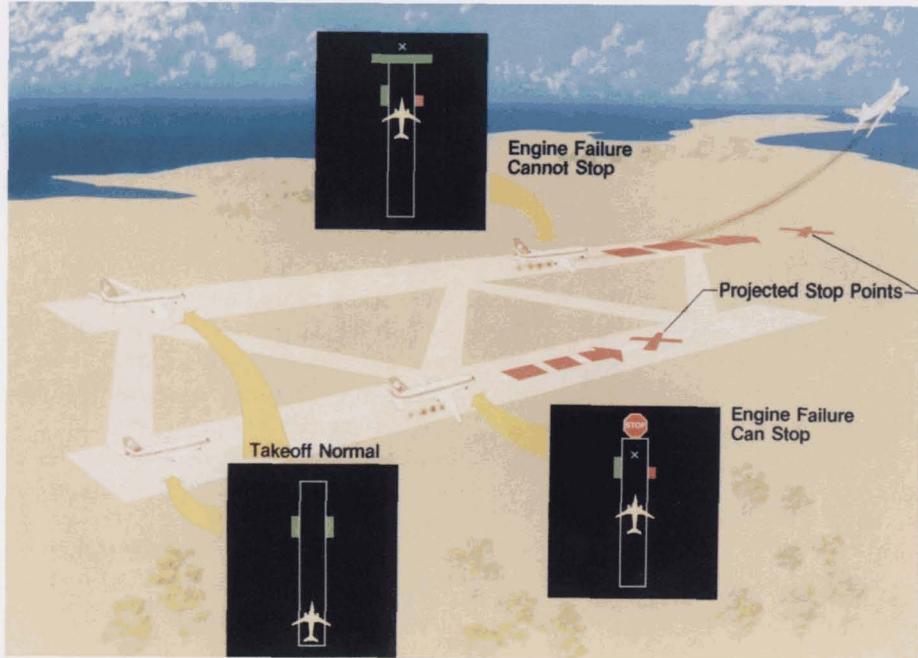
- ▼ The NASA/Lockheed Propfan Test Assessment of a single-rotation advanced turboprop on a Gulfstream II aircraft;
- ▼ The General Electric/McDonnell Douglas flight tests of the UDF on an MD-80 aircraft.

In addition, Pratt & Whitney and Allison have jointly conducted extensive ground tests of a geared counterrotating propfan propulsion system in preparation for flight tests on an MD-80 aircraft.

These flight tests verified the readiness of this advanced turboprop propulsion technology for commercial engine development. These tests also demonstrated the potential for reducing fuel consumption by 25 to 30 percent compared to that projected for future conventional turbofan engines with equivalent engine core technology. This reduction in fuel usage should lower direct operating costs of future transports by as much as 15 percent. As a result, several new engine and aircraft developments are being planned by the U. S. aeronautics industry to take full advantage of this major advancement in aeropropulsion technology.

NASA also has continued to seek advancements in drag reduction for subsonic aircraft. Representative of

Take-Off Performance Monitoring Systems (TOPMS)



these efforts is the cooperative program conducted with Boeing to obtain high Reynolds number data on advanced technology wings for CFD code development. Further efforts are planned which employ laser velocimeter measurements of the wake and local flow. The data provided from these research efforts will aid in developing improved CFD codes.

Laminar boundary layer flow and turbulence control techniques can also significantly reduce viscous aerodynamic drag, thereby contributing to overall aircraft drag reductions of up to 40 per cent. NASA's current hybrid laminar flow control research is concentrated on combining the best features of active laminar flow control and natural laminar flow to achieve significant drag reduction with less system complexity. Other NASA efforts in laminar flow control are detailed in the Aerodynamics Discipline Section.

Research efforts on the Takeoff Performance Monitoring System (TOPMS) completed full-task simulations with 41 experienced multi-engine pilots in 1987. The objective of this program was to provide improved pilot awareness and flight safety during takeoff. The technology developed as a result of this program will enable the pilot to monitor not only the aircraft systems but the outside ambient environment as well. The B-737 flight tests did reveal some problems which were corrected with software modifications. Further flight tests will validate these solutions. The pay-off from this research is the potential reduction in takeoff and landing accident rates.

Other NASA technology programs will find application in the next generation of subsonic transports. For example, the minimization of weather hazards (e.g. wind shear, heavy rain and icing) and cockpit automation, are discussed in greater detail in the Discipline Research Section.

ROTORCRAFT

The nation's continued leadership in military and civil rotary wing technology depends on a strong and broad-based research program. NASA, in cooperation with other government agencies and industry, carries out a rotorcraft program that addresses fundamental research in aerodynamics, structural dynamics, acoustics, guidance, stability and control, propulsion and drive, and human factors. This research is conducted through analytical and experimental programs which focus on critical areas of technological need in order to exploit the full potential of this unique class of vehicles.

Joint programs with the DoD, the Federal Aviation Administration, and the U.S. helicopter industry result in a constructive and closely coordinated national research effort in rotorcraft technology. The U.S. Army and NASA work hand-in-hand on rotorcraft research. This is made possible by an arrangement of collocated Army laboratories at the NASA aeronautical research centers.

Recent emphasis in rotorcraft research has been focused on the acquisition of an extensive rotor airloads data base, high speed rotorcraft technology and tiltrotor research in noise, and vibration control.

A comprehensive rotor airloads program is underway to provide a data base of airloads, blade dynamics, vibrations and acoustics on a modern four-bladed helicopter. A UH-60 Blackhawk helicopter is being used in the flight research program.

UH-60 Blackhawk
Helicopter Supporting Rotor
Airloads Research Program



Pre-flight theoretical predictions using several rotorcraft analytical computer programs have been completed.

The first phase of the flight investigation, which focused attention on the rotor structural limits at high speed, has been completed and government/industry workshops on the effort have been held. In phase two of the investigation highly instrumented rotor blades will be installed. One blade is equipped with 242 miniature pressure sensors to gather airloads data, while another blade has an assortment of 40 strain gages and accelerometers.

In the area of aeroacoustics, NASA is concluding a cooperative program with U.S. industry for noise prediction and reduction. All of the major noise sources have been modeled

and will be incorporated in a global prediction program by the end of 1989. Validation of the analysis has been performed on two helicopters and will continue on the UH-60 and the V-22 tiltrotor. In addition to prediction, innovative noise reduction schemes have been proposed and tested with very promising results.

Vibration reduction is also an area that NASA is aggressively pursuing. Prediction methodologies have been developed to assess rotor and fuselage structural dynamics. Mass tuning of the structure, vibration isolation, and active vibration control techniques are being investigated to reduce vibratory loads. Recently, an experimental assessment of difficult-to-model fuselage components was completed. This data was used to enact solutions which resulted in a significant reduction of higher frequency vibration.

Flight systems and human factors are growing in importance with regard to rotorcraft design. Cockpit

automation for nap-of-the-earth (NOE) flight has received increasing attention from a team of NASA and Army engineers. Ground-based simulations of far-field and mid-field automated NOE algorithms have been successfully accomplished and research is now focusing on the more difficult near-field problem. NASA's helicopter-related human factors research has supported FAA investigations in cooperation with the U.S. Army in evaluating Emergency Medical Service (EMS) operations and pilot decision making, as well as mission management and pilot/vehicle interface research.

In the continuing tiltrotor research effort, a test of a $\frac{2}{3}$ -scale V-22 Osprey rotor in the 40 x 80 ft. wind tunnel at Ames was performed to measure rotor performance in forward flight. The testing also focused on the downloading of the tiltrotor wing in hover. Measurements of the wing download were acquired for a wide range of rotor thrust conditions and wing flap angles. The effects of rotor rotation direction and rotor nacelle angle were also assessed.

This cooperative effort between NASA and the U.S. Navy provided the first large-scale, systematic measurement of tiltrotor, rotor/wing performance and aerodynamic interaction.

In the first detailed survey of tiltrotor noise the XV-15 was flown in a series of tests to gather noise data on the fly-over and approach configurations of the aircraft. The aircraft was flown over an acoustic range at varying airspeeds and rotor



**Large Scale V-22 Rotor
Tests in 40 by 80 ft. Wind
Tunnel**

XV-15 Tiltrotor Research Aircraft



pylon tilt angles. The preliminary results indicate that rotor pylon tilt is a powerful factor in achieving noise abatement in the approach configuration. The noise levels are markedly lower than comparable turboprop aircraft due to the low tip speed of the rotors in the prop mode.

NASA is currently testing an Advanced Technology Blade (ATB) on the XV-15 tiltrotor. This all-composite, highly twisted rotor blade is designed to provide improved hover efficiency and increased cruise speed. Low airspeed test data have shown that hover performance exceeded predictions. As the flight envelope is expanded, the higher speed ranges will be evaluated. Future plans include a comprehensive tiltrotor airloads research program similar to that being done with the UH-60 helicopter.

NASA, the DoD, and the FAA jointly sponsored a study to assess the impact of the V-22 development on the nation as a whole. In February 1988, the FAA/NASA/DoD Steering Group reported on the findings and recommendations of the study.

The study shows that a large potential market exists for civil tiltrotor aircraft. This projected market in high density, short haul city-to-city

operations, has the potential for significantly relieving airport congestion.

Current and planned NASA research will focus on those barrier technologies which must be overcome to allow a civil tiltrotor to be a viable transportation option. Specific barrier areas of interest include noise and vibration reduction, performance and payload improvement, propulsion systems, as well as cockpit automation and control integration.

A major study of the technology needs for high speed rotorcraft has been initiated on both an "in-house" basis and via contract support from industry. Several efforts in the past have sought to combine in a single concept the hover efficiency of the helicopter with the high speed (450+ knots) capability of fixed wing aircraft. These concepts encompass vehicles such as the stopped rotor, stowed rotor, tiltrotors, folding tilt-rotors, X-wing and other hybrid configurations. Many of these configurations, while explored in the past, have not yet been studied in light of new advances in technology.

Current and future developments in the technologies related to composite structures, advanced aerodynamics, digital fly-by-wire controls, advanced propulsion concepts, and new aeromechanical prediction capabilities will be evaluated for use in selected high speed rotorcraft.

SUPersonic

U. S. trade with the Pacific community has increased dramatically, accelerating well beyond the volume of trade with Europe. Mutual security interests are also of increasing significance. Consequently, long-range supersonic cruise aircraft are strategically and economically important to U.S. national interests.

Passenger aircraft that feature 350-passenger capacity, trans-pacific range, and cruise speeds of two to four times the speed of sound will someday link the farthest reaches of the Pacific Rim area in four to five hours. Military applications will provide vital strategic advantages in basing, long-distance responsiveness, and survivability.

A major technological challenge in this area is to develop variable cycle propulsion systems that will meet acceptable engine emission and noise standards and provide a substantial reduction in fuel consumption while offering extended engine life at high, sustained operating temperatures. Other challenges include reducing the airframe structural weight fraction, and increasing the cruise lift-to-drag ratio via supersonic laminar flow, and developing technologies to alleviate the impact of sonic boom.

NASA has defined a High Speed Research Program, to address the barrier issues which must be resolved to pave the way for further research into high speed transport technology. The key element to the program is developing a better understanding of the environmental impacts of a fleet of high speed civil transports operating around the world.



High Speed Civil Transport (HSCT) Concepts

With cooperative efforts from atmospheric scientists in NASA and abroad, the program will conduct research in the key areas of: atmospheric impacts, airport noise, sonic boom effects and low emission combustors. With acceptable levels of chemical emissions and noise signatures, the program will focus more heavily on the technology validation aspects of the program.

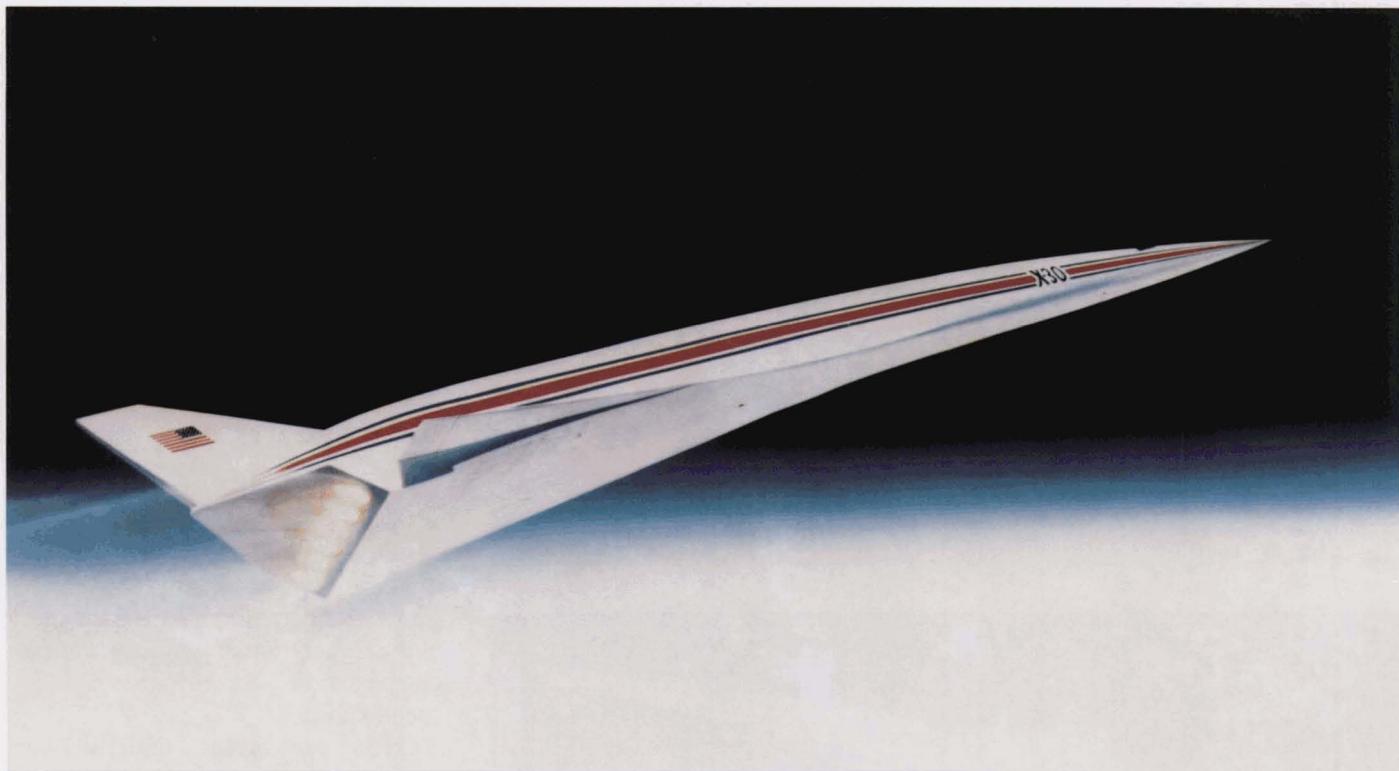
In aerodynamics, increased effort has been focused on the feasibility of achieving substantial reductions in drag by retaining a laminar boundary layer at supersonic speeds.

In materials and structures, research efforts have concentrated on the development of advanced composite and ceramic materials for the high-temperature environment in the engines and on the airframes of high speed vehicles.

Studies are currently underway that indicate major improvements are possible for supersonic aircraft engines by the application of advanced high-temperature materials. Research efforts have also been initiated to investigate the feasibility of achieving supersonic flow through aircraft turbofan engines.

To improve the operational efficiency and safety of all aircraft, systems research efforts are now underway to develop automation technology incorporating artificial intelligence for flight optimization. This can be particularly valuable for future high-speed transport aircraft because of their large fuel load requirements and relatively small payload fractions.

Artist's Concept of the X-30



HYPersonic TECHNOLOGY

One of the key technology thrusts of the aeronautics program being pursued by NASA is the technology foundation for hypersonic vehicles. The program focuses on vehicle configuration studies, propulsion, and materials and structures. Recent accomplishments in these areas, combined with earlier progress in hypersonic research and space flight experience, established the foundation for the National Aero-Space Plane (NASP) program. The NASP program, which has been jointly funded by DoD and NASA, focuses technology development toward a flight research vehi-

cle, the X-30, which will be used to validate and demonstrate the successful integration of aeronautics and space technologies across the speed range from takeoff to orbital velocities.

This merging of aeronautics and space technologies into an aerospace vehicle powered by an airbreathing propulsion system, provides the potential for an entirely new class of flight vehicles for the next century, ranging from hypersonic aircraft to a single-stage-to-orbit space transportation system. These vehicles would have the ability to take off from and land on conventional runways, sustain hypersonic cruise flight in the atmosphere, or accelerate into space. The transatmospheric capability, made possible by this technology, will greatly enhance the operational potential of both military and civil aircraft and significantly cut the cost of delivering payloads to orbit.

The technical challenges of an aerospace plane are formidable and the list of essential technologies is long. The program's extensive computational fluid dynamics work has begun to consume 60% of the aerospace supercomputer capability.

The potential advantages which could accrue from NASP for application to future vehicles include the following:

- ▼ On-demand access to space
- ▼ Airplane-like horizontal take off and landing (HTOL) operations out of widely dispersed, existing airfields
- ▼ Operational flexibility, which comes from airbreathing propulsion, in the form of self-ferry, offset orbits and mission abort/recall capability

- ▼ Significantly reduced long-term operational costs due to total vehicle reusability
- ▼ Greatly reduced ground turn-around time

To achieve these capabilities, the X-30 must serve as the vanguard, flying ascent trajectories with aerodynamic heating levels considerably higher than those encountered by rocket powered vehicles. It will not use fragile ablative materials or insulating tiles to protect the primary structure, instead it will utilize actively-cooled structures.

Even with active cooling, however, the X-30 requires the use of primary structural materials capable of withstanding significantly higher temperatures and offering much improved specific strength and stiffness. Since the X-30 will encounter dynamic pressures as high as 2000 psf with the need for precise flight path control, new integrated flight/propulsion controls and guidance systems must be developed which afford major improvements over the Shuttle and current aircraft state of the art.

The most difficult technology development in the NASP program is the airbreathing propulsion system, its structure and cooling system. It is required to operate efficiently over the speed range from take-off into the high hypersonic regime (Mach 15-20) with minimum engine weight. The development of this propulsion system must be accomplished with test facilities which are greatly limited in capability compared to the conditions of flight. Ultra modern computational fluid dynamics (CFD) analytical tools, coupled with the best test data available, will be used to extrapolate conditions for design to the highest speed. Ultimately, the X-30 itself will become a flying test

facility for the validation of technologies and final proof of performance. The timely expansion of the X-30 flight envelope with incremental probing of the thermal environment will help assure the emergence of a new generation of U. S. space vehicles, significantly ahead of foreign competition.

NASA's expertise in hypersonic technology is being fully applied to NASP with the realization that its extremely broad range of technological needs challenges all disciplines with no exceptions. All future hypersonic vehicle concepts (hypersonic cruise transports and military aircraft, missiles, reusable advanced launch vehicles, etc.) will be designed with fallout from NASP.

In the past several years, NASA has been supporting NASP with technical manpower, management expertise, computational capabilities and hypersonic test facilities, and a great deal of progress has been made.

Some of the major accomplishments are:

- ▼ Three-dimensional full Navier-Stokes analyses of the propulsion flow path with real gas and combustion chemistry effects. These analyses continue as new designs develop. Advanced turbulence modeling efforts and extensive experimental validation of codes is underway.
- ▼ Major direct-connect and free-jet tests have been completed on exploratory engine models and NASP contractor designs at hypersonic conditions.
- ▼ Major advances are being made in scramjet mixing and fuel injection techniques.
- ▼ Significant advances are being made in analytical performance prediction and development of high-temperature metal matrix composite materials, titanium aluminides, carbon composites, and other materials.



Hypersonic Inlet Under Test
for Validation of CFD
Analytical Codes

- ▼ The Hypersonic 3.5 ft High-Temperature Wind Tunnel, the ballistic range, and arc-heated test facilities at the Ames Research Center are again operational.
- ▼ The full range of wind tunnels (Mach 0.2-20) at the Langley Research Center are being used extensively for NASP. The modification of the 8 ft High-Temperature Structures Tunnel to provide oxygen enrichment for hypersonic propulsion testing is nearing completion.
- ▼ A large-scale two-dimensional hypersonic engine inlet is undergoing extensive testing at the Lewis Research Center to investigate methods for controlling the internal boundary layer at Mach numbers up to 5 and to provide viscous flow data for CFD code validation.
- ▼ Advanced high-temperature light weight structural concepts have been developed along with plans for validation testing. Requirements on these structures include carrying basic mechanical loads, containing and insulating the cryogenic hydrogen fuel, and allowing for major thermal stresses and strains.

- ▼ Extensive analyses and tests have been completed which quantify the critical thermal loads associated with the interaction of shockwaves with leading edges and wall boundary layers.
- ▼ Research in hypersonic boundary-layer transition, which is critical to eliminating unneeded conservatism in NASP, is resulting in an improved understanding of the mechanisms of hypersonic boundary-layer transition through "quiet" wind tunnel investigations at Langley. Prediction methods are currently being developed for application to increasingly higher Mach numbers.
- ▼ Test techniques are being developed, demonstrated, and standardized at Langley for installed propulsion performance of NASP vehicle designs at Langley.
- ▼ The Numerical Aerodynamic Simulation Facility at NASA-Ames is being heavily utilized for extensive NASP CFD computations.

The successful completion of this major technical thrust into the hypersonic flight regime will ensure United States preeminence in aeronautics and space vehicles of the future. In order to achieve their success, the momentum which has built up with the introduction of NASP must be sustained in order to guarantee the breakthroughs that are needed to bring efficiency and economic viability to future civil vehicles. The technical staff and test facility assets of NASA will continue to make important contributions to the critical progress.

HIGH PERFORMANCE

NASA's high performance aircraft research program is an integral and critical part of the overall aeronautics program. This program is structured to develop and mature technologies that have both important military and civil applications. Historically, NASA and the military have worked closely together to identify and develop aeronautical technologies which require flight research in order to explore, validate, and mature the technologies for application in a military aircraft. These technology programs are carefully selected to demonstrate a significant improvement in performance or to show a new capability that has high payoff.

NASA has also traditionally had a role in applying its knowledge, people and facilities to assist the military in solving challenges encountered with operational aircraft. It is well recognized that certain synergies exist between military and civil technological developments. For instance, military requirements generally strive to expand the flight performance envelope while civil sector requirements tend to concentrate on lower production costs, improved maintainability, and higher reliability. This synergy, in turn, generally results in military aircraft being more affordable and civil aircraft having increased performance.

Vortex Flow Visualization
on HARV in Flight



Supermaneuverability

Several years ago, NASA accelerated the technology necessary to provide high performance aircraft with the capability to achieve stable and controllable flight at angles-of-attack approaching 90 degrees to the free stream airflow (also referred to as high-alpha flight).

Achieving stable and controllable flight at these extreme attitudes offers dramatic payoffs in aircraft agility,

performance, and safety. Collectively the technology is referred to as "supermaneuverability."

Unprecedented high angle-of-attack, or "high-alpha," capabilities utilizing propulsive control concepts were demonstrated with free-flying wind tunnel models and simulation studies.

In April 1987, a full-scale flight research program was initiated utilizing a modified Navy F-18 aircraft. The F-18 High-Alpha Research Vehicle (HARV) has many instruments specifically designed to obtain research-quality data in support of a coordinated analytical, wind tunnel, simulator, and flight research program. The objective of the program is to develop, refine, and verify the predictive techniques and design meth-



Oil Flow Visualization on HARV

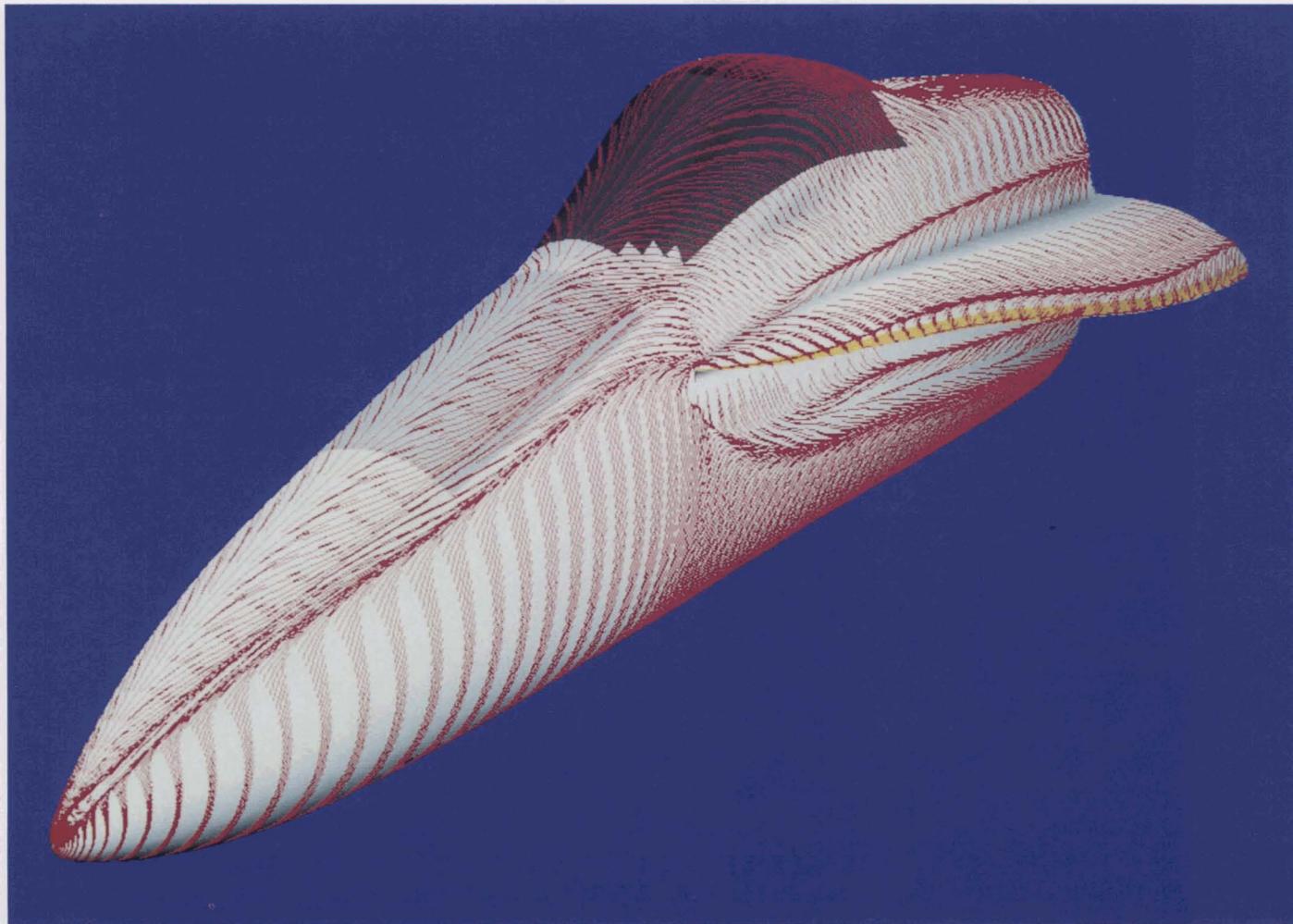
ods for future supersonic aircraft capable of unprecedented agility and maneuverability throughout the air combat flight envelope. Phase I, in which the aircraft was successfully flown to 50-degrees angle-of-attack, has been completed. These results have been correlated with data from computational analyses and wind tunnel tests.

The F-18 HARV will be modified for thrust vectoring/propulsive control to permit the research aircraft to attain controlled flight at angles-of-attack up to and beyond 70 degrees.

Unique flow visualization systems for the F-18 HARV have been developed which allow direct observation of the separated flows throughout a wide range of flight conditions. The aircraft is equipped with a specially developed smoke generator, an oil flow generator, onboard photographic and video systems, and instrumentation. Smoke is discharged through nose ports and is then entrained into the low-pressure core of the vortices which occur at high angles of attack. Breakdown of the vortices is indicated by the rapid diffusion of the smoke. The resulting pattern is tracked using both photographic and video images and is correlated with measured flight conditions.

The system has been designed, developed, and checked in flight, and is being used as a research tool. Successful operation has been demonstrated at altitudes up to 30,000 feet, at speeds up to Mach 0.6, and at angles of attack up to 50 degrees. Recorded visual information has been translated into vortex core locations with respect to the aircraft coordinate system. This process involves some subjective interpretation of the image data. This limitation is being overcome by the use of digitized versions of the recorded images.

**CFD Simulation of
Streamlines on F-18
Forebody**



Through the use of both smoke and oil flow visualization techniques the vortices generated on the forebody of the F-18 at high angles-of-attack were documented in flight.

In a parallel analytical effort, the surface flow patterns were computed in the process of developing a capability to understand and predict the separated flows generated on aircraft forebodies at high angle-of-attack.

With the significant CFD capability that now resides within NASA, these detailed surface flows over the forebody leading edge extension can be calculated with Navier-Stokes turbulent flow solutions.

Initial comparison of the computational solutions with flight-test results show good first-order prediction of forebody flows. In the future it is intended to add the capability to model the entire aircraft to determine the effect of forebody flows on the vertical tail surfaces and to simulate forebody control surfaces for advanced lateral-directional control systems.

These flight tests are now providing data to correlate with previous wind tunnel investigations conducted in the Basic Aerodynamics Research Tunnel (BART) at the Langley Research Center. In that effort a laser light sheet was used to illuminate the strake and forebody flows to better understand these phenomena. The vortex breakdown pattern and associated vertical tail buffet loads observed in the wind tunnel tests are currently being studied using three component laser velocimeter data.

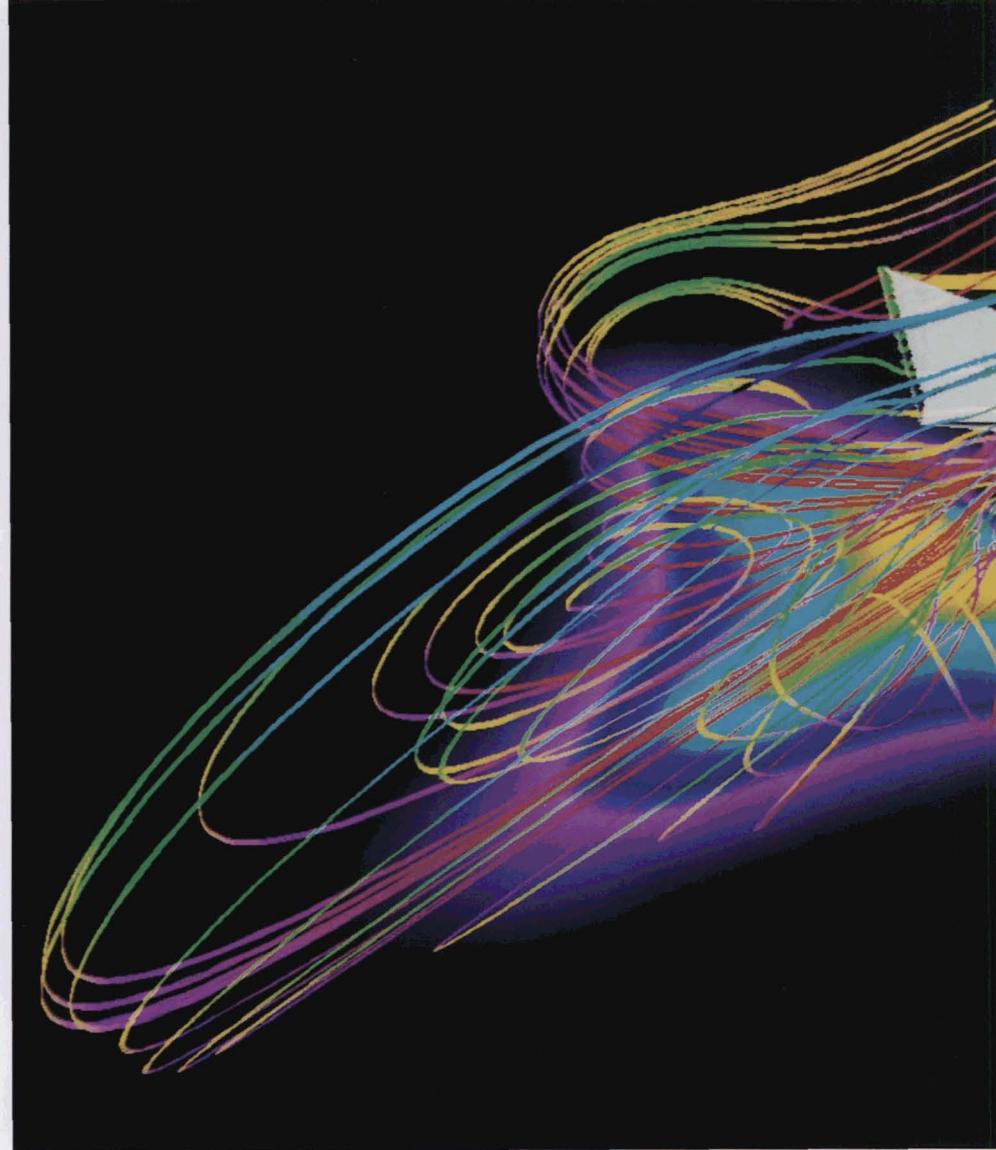
STOVL Hot Gas Ingestion Model in LeRC Wind Tunnel



STOVL

Advances in propulsion system thrust-to-weight ratios, propulsive lift control, and the understanding of low speed aerodynamics now combine to open new opportunities for state-of-the-art advances in new short take off and vertical landing (STOVL) aircraft.

The United States and the United Kingdom are mid-way through a four year program to develop advanced STOVL (ASTOVL) technologies aimed at reducing the technological risk associated with development of ASTOVL aircraft. One technology thrust was to develop airframe configurations that minimize the hot gas ingestion from the propulsion system recirculating back into the engine inlets, resulting in hover performance degradation. An experimental activity was initiated at the Lewis Research Center's 9 X 15 ft. low speed wind tunnel to develop the analytical capability to predict when reingestion will occur and to provide verification for newly developed CFD codes. The testing focused on the evaluation of

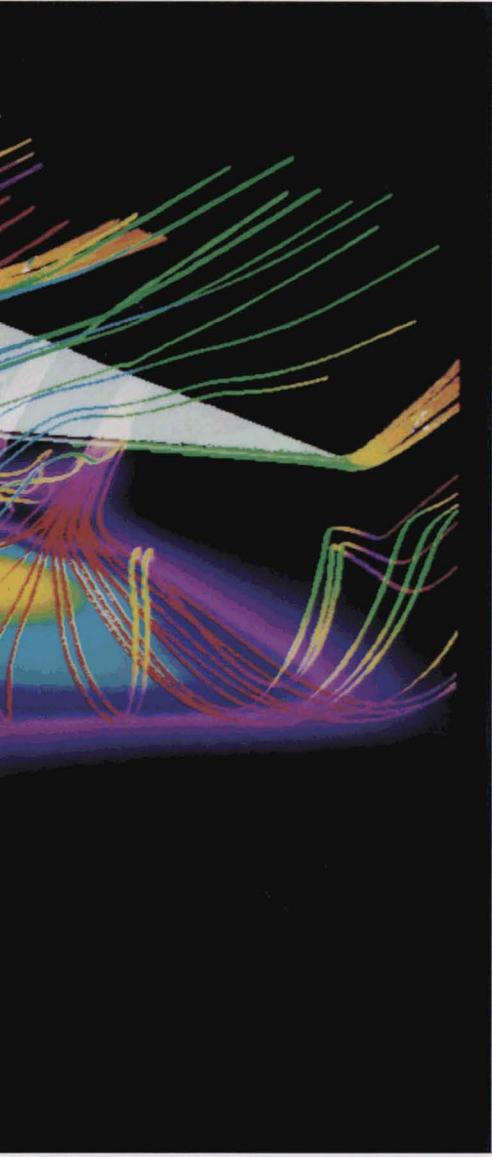


engine inlet temperature distributions and exhaust gas deflection methods. Initial testing was accomplished using a vectored thrust model with simulated exhaust gases at 500 degrees F at forward flight velocities of zero to 100 knots.

Another aspect of powered lift research currently receiving attention is the effort to provide an analytical capability to understand and predict lift losses induced by vectored thrust

during ground proximity operation. Navier-Stokes solutions have been developed for flat-plate delta wing configurations in close proximity to the ground. Initial comparisons of the computational solutions with experimental results produced good first-order prediction of wing lift in these conditions.

CFD Simulation of Delta Wing with Vectored Thrust in Ground Effect



V/STOL Concept in 40 by 80 ft. Wind Tunnel



NASA continues, in a joint venture with Canada, to build and test a full-scale STOVL wind tunnel model. The model, an E-7 transonic aircraft configuration, utilizes an ejector thrust augmentation system for low speed STOVL operations.

A full-scale model of the E-7 was tested in the 40 X 80 ft. wind tunnel located at the Ames Research Center. Preliminary data indicate that the hover to forward flight transition can be successfully completed.

The YAV-8B Harrier, otherwise known as the VSRA (Vertical/STOL Research Aircraft) is being used in a broad flight research program critically important to advancing STOVL technology. This program, at the Ames Research Center, is carrying out experimental verification and validation of integrated flight/propulsion controls, advanced cockpit display concepts, and advanced control methodology.

V/STOL Systems Research Aircraft (VSRA)

X-29A Forward Swept Wing Aircraft





Forward Swept Wing Technology

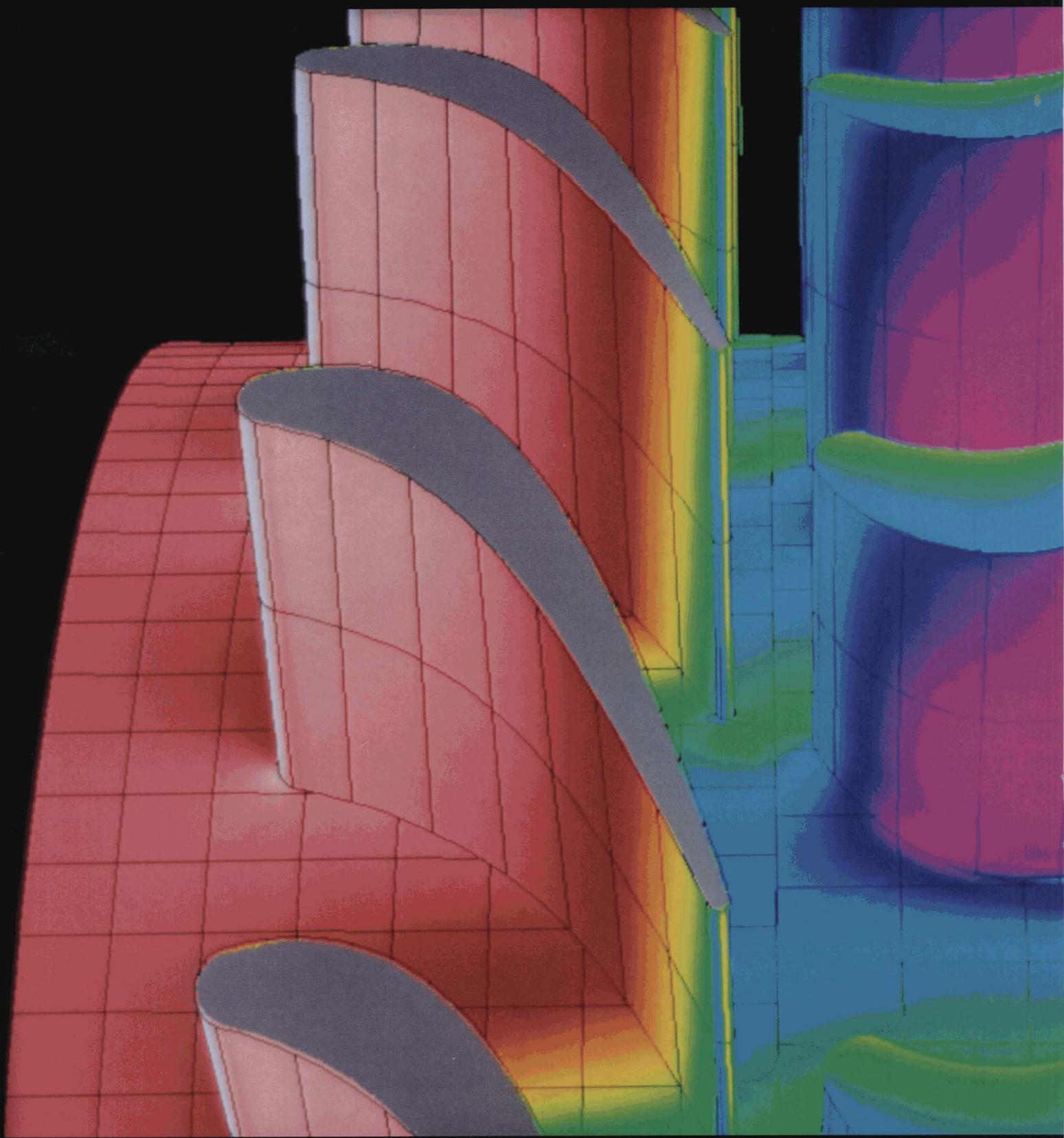
In 1980, NASA, the Air Force and the Defense Advanced Research Projects Agency embarked on designing, building and testing a forward swept wing (FSW) fighter-class aircraft. This design was projected to offer both performance advantages and a new option in configuration integration. Concurrently, the opportunity was seized to test several other emerging technologies of high potential. These included relaxed static stability; three surface longitudinal control; aeroelastically tailored, composite, thin supercritical wing; close-coupled wing and canard; and digital flight control system.

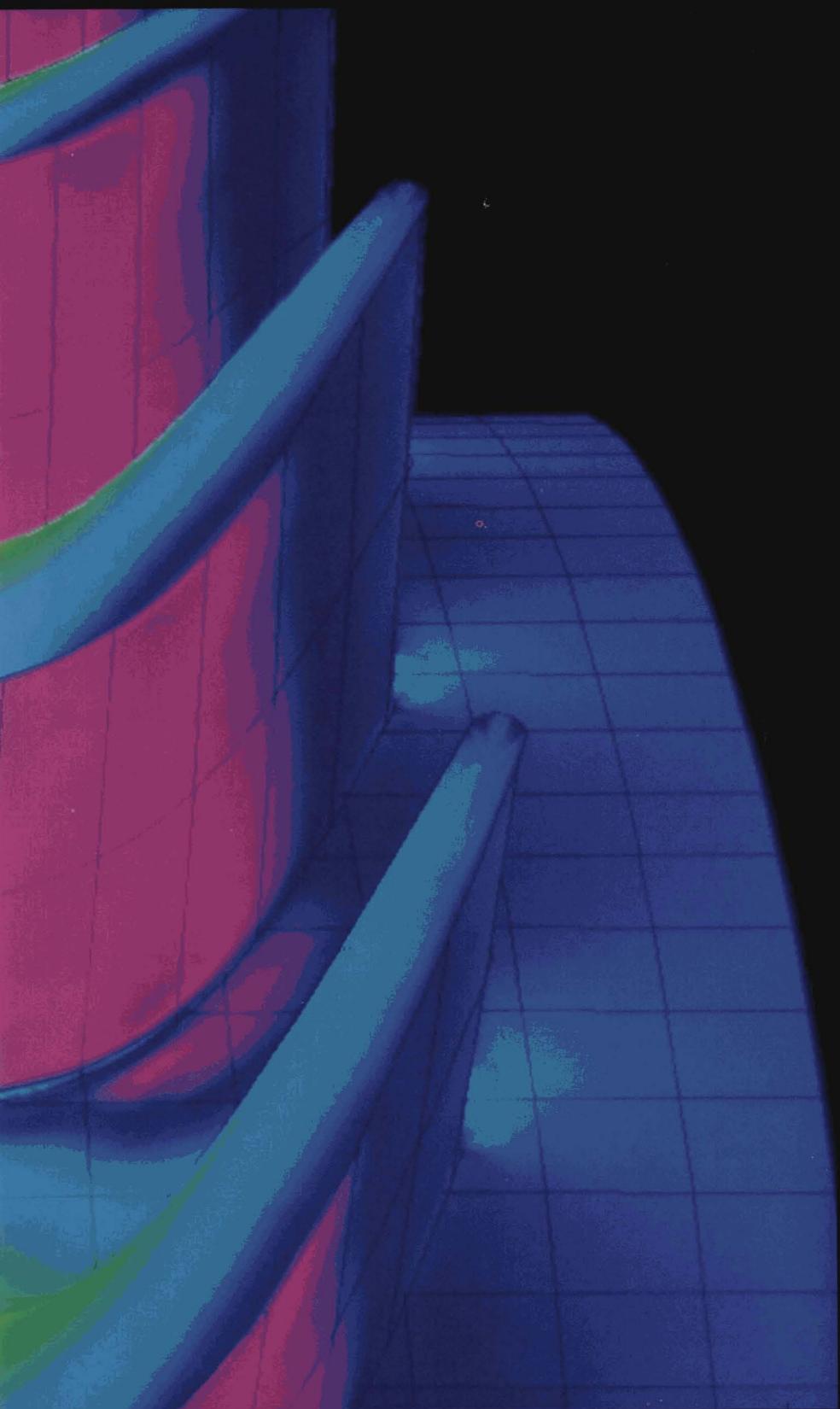
Two X-29A forward swept wing research aircraft were fabricated, although only the first aircraft has been used in the flight research program to date. The concept demonstration and flight envelope expansion phase was completed in 1987. The flight research program utilizing the X-29A No. 1 aircraft is now completed. Over 240 flights of the No. 1 X-29A aircraft were performed between December 1984 and December 1988, with over twenty pilots providing their critical assessment of the aircraft's performance and capabilities.

The results demonstrated to date have verified that FSW aircraft can save 10 to 20% in drag and 5 to 25% in weight over current designs. The results have proven the feasibility of flying an aircraft with 35% negative static stability through the application of full authority, closed-loop control of the close-coupled wing

and canard. The program has also established the design techniques for the successful aeroelastic tailoring of composite wings and the integration of digital fly-by-wire control systems with three surface pitch control. The second X-29A research aircraft is currently being prepared for evaluation of high angle-of-attack flight characteristics. This program will evaluate the advanced FSW technologies in maneuvering flight at angles of attack above 20 degrees.

DISCIPLINE RESEARCH





AERODYNAMICS

The NASA aerodynamics effort provides the technology base upon which vehicle advancements can be made throughout all speed regimes and aerospace vehicle classes.

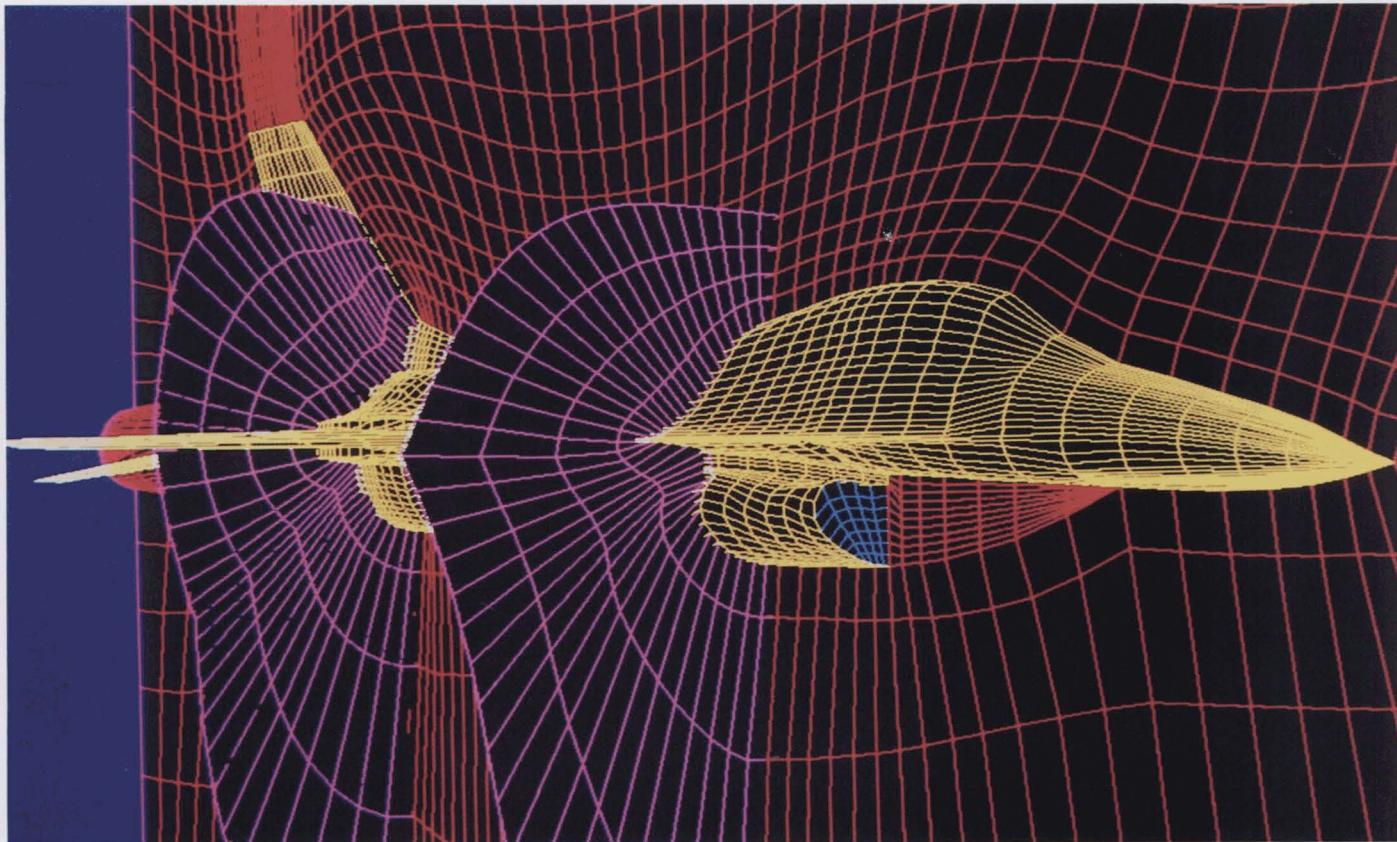
The disciplinary research in aerodynamics is structured in a program of closely integrated efforts in theoretical analyses, numerical simulation, wind-tunnel testing, instrumentation development, and selected flight research projects.

A major emphasis is placed on the development and validation of Computational Fluid Dynamics (CFD) methods and codes to advance the understanding and prediction of complex aerodynamic phenomena. Research includes flow diagnostics using modern CFD tools, specifically Navier-Stokes/Euler computations to improve the understanding of the detailed mechanisms associated with induced drag. This research is made possible by the new computational power of the large Numerical Aerodynamic Simulator (NAS) supercomputer facility now available in NASA.

The discipline of Computational Fluid Dynamics is continuing to provide powerful analytical, simulation, and predictive tools to describe the complex physics of aerodynamic flow. Significant advances have been made in the areas of grid generation and the application of CFD to specific problems. These advances coupled with the increased capabilities of advanced supercomputers have provided the technology for a better

CFD Simulation of Pressure Distribution on Engine Turbine Stage

**Computer Generated Grid
Representation of F-16**



understanding of the complex flow environment of advanced aerospace configurations and for the simple integration of multidisciplinary solutions.

The development of structured, multi-block grids was used to model an experimental cranked-wing fighter. This application combined the internal flow through the engine duct with the external aerodynamic flow using a unified Euler code. The grid for the engine duct was embedded in an overall grid and the solution was accomplished using conservative interfacing techniques. A similar multi-block method was utilized to completely model the F-16 aircraft using a Navier-Stokes code.

The application of CFD to simulate the flow over advanced aerospace vehicles has included the study of vortex breakdown over a double delta wing and the prediction of flows induced by vectored thrust during operation in proximity to the ground.

Vortex breakdown was predicted when the grid was defined using at least 800,000 grid points. Coarser grids did not capture the fundamental physics of the vortex core and did not indicate vortex breakdown.

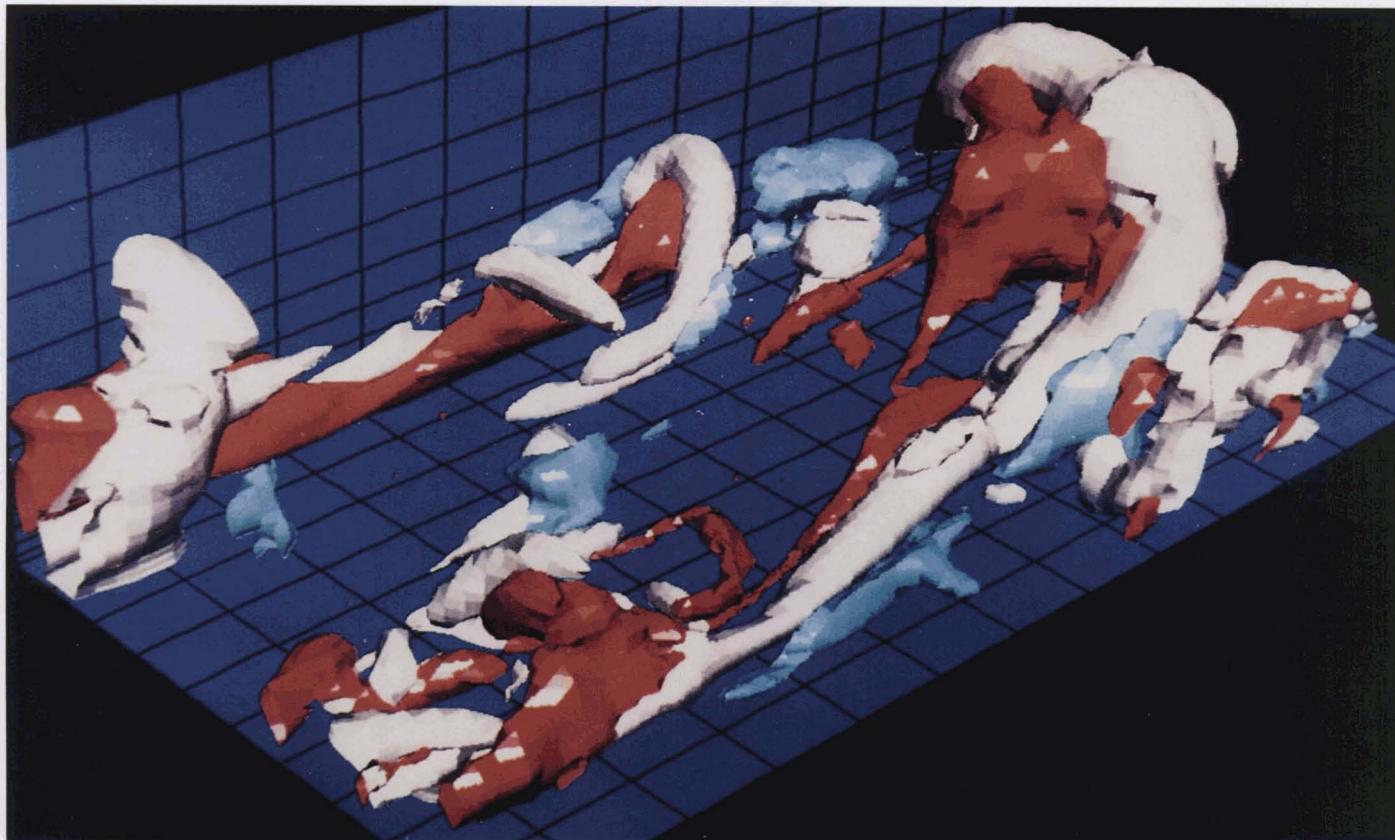
Recent accomplishments using CFD to study aerodynamic flow include the use of a Reynolds averaged Navier-Stokes code, F3-D, and a high resolution grid, to analyze the vortex breakdown over a double delta wing. The vortex flow was successfully predicted for high angle-of-attack opera-

tion at Mach 0.3 and a Reynolds Number of 1.3 million. Three-dimensional particle paths above the double-delta configuration clearly showed the vortex breakdown mechanism.

In addition, the Navier-Stokes solution for a flat plate delta wing with two simulated jets issuing from the underside of the wing in the presence of the ground has compared favorably with experimental results.

In other studies, direct numerical simulation of the flow in a channel has produced valuable insights into the physical mechanisms which lead to the development of turbulent

**Numerical Simulation of
Boundary Layer Turbulence**



flows. The structure of the turbulent flow is illustrated in the adjoining figure. The elongated white surfaces identify the low-pressure vortex cores. The red areas represent low speed fluid being ejected outward away from the wall, and the blue areas indicate the high speed fluid being swept towards the wall.

Since induced drag accounts for nearly 50 percent of the cruise drag and as much as 70 percent of the climb drag of most current aircraft, significant improvements in aircraft fuel efficiency and climb performance can be achieved through induced drag reduction. Recent theoretical and experimental studies have shown that lifting surface platforms which have a crescent shape or sheared wing-tips can provide a significant reduction in induced drag.

These discoveries have been made using modern nonlinear computational methods which can more properly account for the effects of the deflected and rolled-up wake on platform optimization, and have been validated in careful wind tunnel tests.

The Numerical Aerodynamic Simulation (NAS) facility continues to provide advanced supercomputers available for computational simulations of aerospace vehicles. The NAS facility was dedicated on March 9, 1987 and is currently supporting over 1100 users at over 110 sites.



Three Dimensional Particle Paths of a Double Delta Configuration

Cray Y-MP Computer

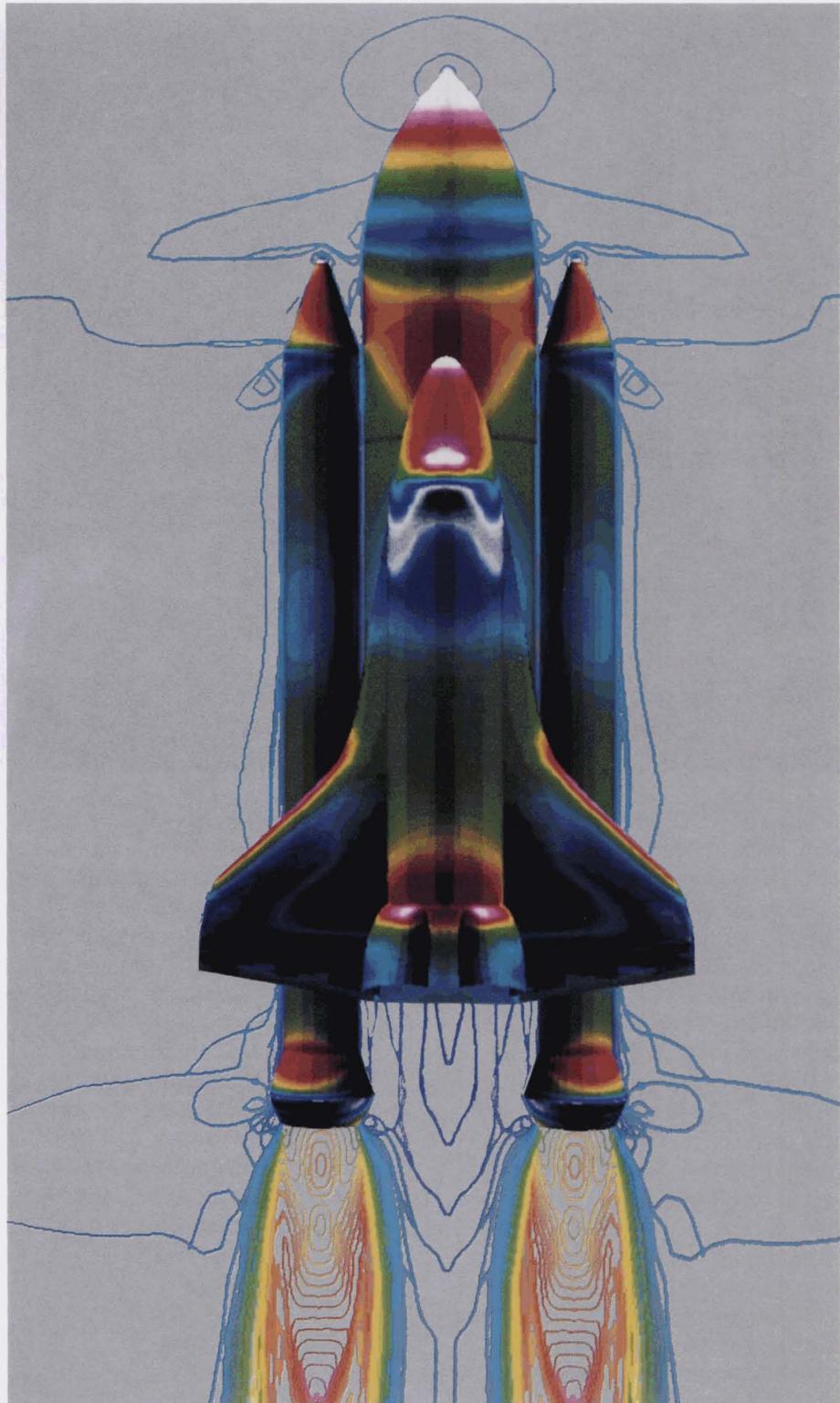
Currently, the NAS facility houses both a Cray-2 supercomputer and a Cray Y-MP supercomputer. The Cray Y-MP is over four times faster than the Cray-2 a with sustained performance of over one billion floating point operations per second (1 GFLOP).

Networking continues to be a key element of the NAS capability. High speed data links are installed from NASA installations with medium speed links installed to all major aerospace companies. In addition, the NAS facility is interconnected with ARPANET, NSFNET, and other national networks. The NAS capability has been developed with the goal of providing service and capability to remote and local users equally.

The NAS capability now provides improved modeling of the Space Shuttle in the ascent configuration. This simulation was developed to analyze the complete shuttle launch configuration, including the relative motion of the orbiter when released from the external tank.

The flow over the Shuttle, solid rocket boosters, and external tank is shown in the figure along with the exhaust plume from the solid rocket engines. The results show favorable comparison with experimental data.

As part of the F-14 Variable Sweep Transition Flight Experiment (VSTFE),

Flow Simulation of the Space Shuttle in the Ascent Configuration

**Natural Laminar Flow
Research on F-14 Aircraft**

viscous flow studies were performed based on an F-14 aircraft wing with a natural laminar flow glove. These tests defined the effects of wing sweep on the laminar, turbulent flow transition characteristics and the resultant increase in aircraft skin friction drag.

NASA has also initiated research in supersonic laminar flow. The nemesis in meaningful wind tunnel testing at supersonic speeds has been the very high noise level in the supersonic wind tunnel test sections at Mach numbers around two and above. Langley Research Center has developed a quiet supersonic nozzle and successfully demonstrated its operation in a pilot wind tunnel. The capability of this facility is limited due to its small size, but it has provided important test results which validated a long held, but previously unsubstantiated, viscous flow theorem which postulated that two-dimensional flow is inherently more stable than three dimensional flow. These results have significant application to the overall airframe design for hypersonic flight. A larger tunnel employing the quiet nozzle concept is planned for the future.

The use of flight test experiments to substantiate the supersonic laminar flow wind tunnel results will be performed with two F-16 XL aircraft recently acquired from the Air Force. Both laminar and turbulent supersonic drag reduction studies will be performed with the F-16s.

The computational analysis of laminar flow stability in both the subsonic and supersonic regimes is an active area of research. This work includes determining the sensitivity of the laminar boundary layer to external stimuli and studying the propagation of these disturbances through the fluid.



Stability theory concepts are being extended into the complex, nonlinear portion of the transition-to-turbulence process to better understand the mechanisms involved in this process more precisely and to predict the occurrence of transition. In a cooperative effort with Gulfstream Aerospace Corporation, a full-scale, semi-span wing model was installed in the 30 by 60 ft. wind tunnel at the Langley Research Center. This was the first test of a Natural Laminar Flow (NLF) wing with a single-slotted flap. The model, incorporating a wing/flap system developed by Langley, was designed using advanced CFD codes. These low speed tests focused on the high-lift characteristics of the wing and the data is currently being used to validate NLF design methods.



F-16XL Research Aircraft

PROPULSION

Advanced propulsion technology is the key to realizing major improvements in new aeronautical vehicle concepts.

Propulsion system technology must be built upon a solid base of focused discipline research in the areas of Internal Fluid Mechanics (IFM), advanced control concepts, and new instrumentation techniques.

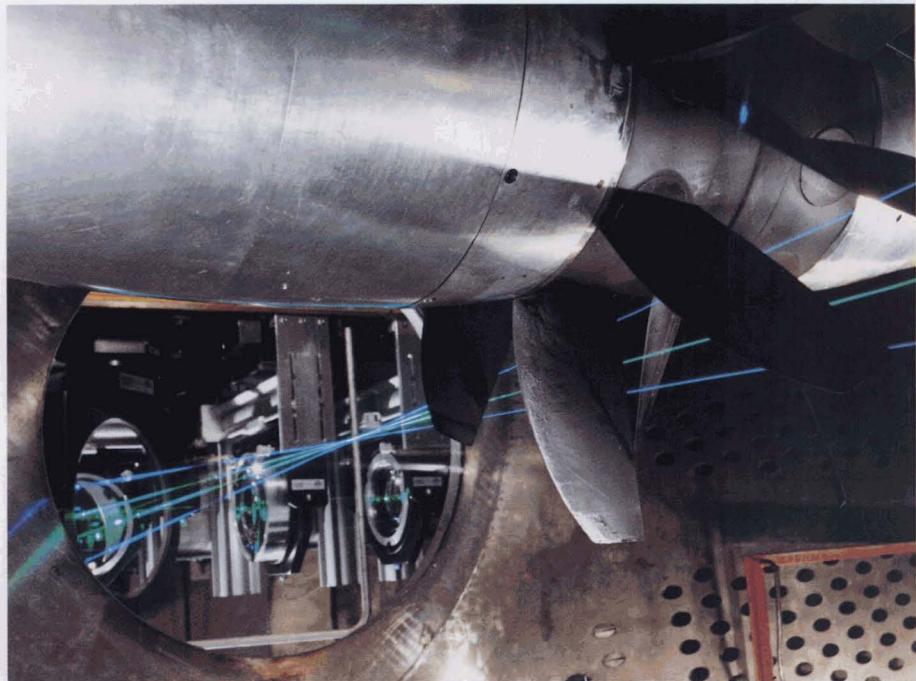
Hypersonic flight is critically dependent upon new propulsion concepts. Future supersonic cruise and subsonic transports will benefit from more efficient propulsion systems. In addition, the development of high speed rotorcraft and more fuel efficient general aviation aircraft require new, innovative propulsion concepts.

The scope of propulsion research at the Lewis Research Center includes small turbine engines, powered lift concepts in support of Advanced Short Take-Off and Vertical Landing (ASTOVL) aircraft configurations, as well as propulsion for supersonic cruise and hypersonic aircraft.

Rotary cycle engines for general aviation and convertible propulsion systems for high speed rotorcraft applications are elements of the current aeropropulsion program. Combining these concepts with new high temperature materials and structures offers advances in propulsion technologies which are critical to the successful development of these new vehicles.

Discipline research in internal fluid mechanics is providing the analytical tools to describe the complex flow in turbomachinery, high speed inlets, exhaust nozzles and ducts, and chemically reacting flows in combustors. The ability to analyze two-di-

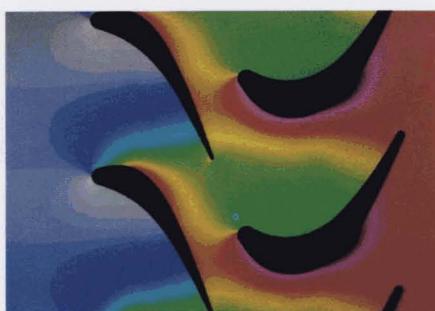
Laser Velocimeter Flow Field Measurements of Advanced Turboprop Model in Wind Tunnel



mensional chemically reacting flows in converging-diverging ducts for ramjets and scramjets was recently demonstrated by the Lewis Research Center and released to industry.

Another example of the internal fluid mechanics tools being developed by the NASA Ames Research Center is the rotor/stator code. This model performs one of the most complex simulations ever developed, involving more than 22 trillion computations on a Cray-2 supercom-

puter, part of the NAS facility at Ames. The NASA model is the most detailed description of the airflow within turbines yet developed, providing the precise analysis of interior changes in pressure, temperature, and velocity tracked in three spatial dimensions over time. Because of the tremendous amount of data (a single simulation may provide 2 billion data points) high-speed computer graphics are being used to visualize the calculated flow patterns.



Numerical Simulation of Rotor/Stator Interactions.

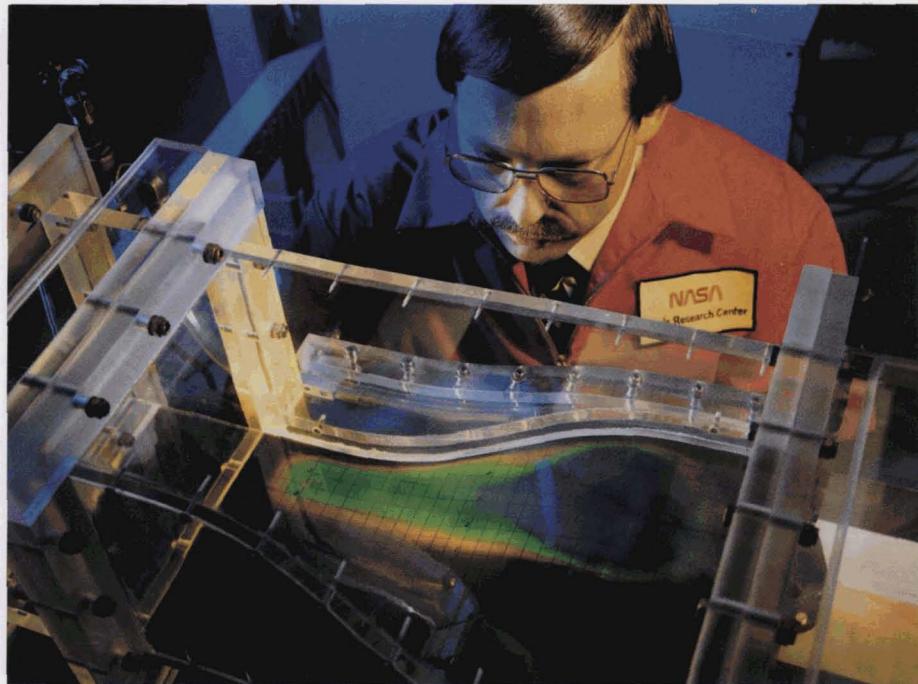
While the simulation is now valuable as an analytical tool, the execution time of the model must be reduced to make it practical for design optimization applications. It is expected that within 3 to 5 years the execution time can be reduced from the current levels of 100 hours on a supercomputer to approximately 10 hours, depending upon the computational speeds attained by future supercomputers and further development of the model to improve the computational efficiency of the code.

Laser velocimetry has become a valuable experimental technique for acquiring unobtrusive, detailed internal flow measurements in turbomachinery. By combining an interferometer and a conventional laser velocimeter into a single optical system, the instrument is capable of measuring three velocity components using two laser beams and requires only a single port for optical access to the internal flow.

An earlier version of this system was used to investigate the flowfield generated by an advanced counterrotating pusher propeller model similar to the full-scale Unducted Fan demonstrator engine. The model, equipped with two foot diameter propfans, recently completed aerodynamic, acoustic, and aeroelastic testing at cruise conditions up to Mach 0.85. The tests were performed in the 8 x 6 ft. supersonic wind tunnel at the NASA Lewis Research Center.

High temperature instrumentation technology is a key element in achieving substantive advances in propulsion technology. Significant progress was made during 1988 in the development of high temperature semiconductor technology with the demonstration of the ability of silicon carbide devices to retain diode

NASA-Developed Heat Transfer Measurement Technique



characteristics up to 550 degrees C. The devices were manufactured from silicon carbide crystals grown at the Lewis Research Center. Silicon carbide is, therefore, a promising instrumentation material for use in aeropropulsion experimental rigs and in operational engines. These characteristics also make silicon carbide a potential candidate for use in the high temperature environments experienced by spacecraft.

In addition, experiments have been conducted using liquid crystal techniques to measure heat transfer coefficients in a transient low temperature heat transfer tunnel. These measurements will be used to validate 3-D viscous heat transfer codes being developed to predict heat transfer on complex surfaces. The main advantage of the transient heat

transfer technique using liquid crystals is the acquisition of high resolution measurements on complex shapes without the necessity of actively heating the model.

NASA has also completed fabrication of a large, low-speed centrifugal compressor test facility at the Lewis Research Center. This facility is being used to develop a fundamental understanding of viscous flow regions and secondary flows which dominate centrifugal turbomachinery flows. The five foot diameter compressor rotor, operating at 1950 rpm, yields viscous flow regions 10 times larger than typical compressors, allowing measurements to be obtained with more detail and greater accuracy. This facility allows pressure, temperature, and flow velocity data to be obtained simultaneously for both steady and unsteady flows. These results will be compared with high-speed compressor measurements and used for IFM code development and validation.

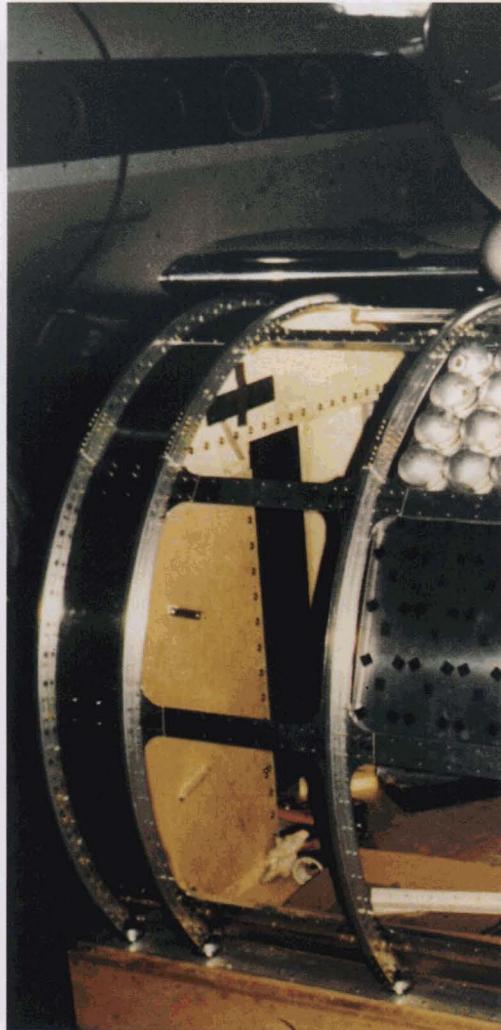
**Large Low-Speed
Centrifugal Compressor
Research Facility**



Intermittent Combustion engines offer potentially lower cost for general aviation and commuter aircraft applications. In the past these aircraft have been restricted to the use of aviation gas which has become difficult to obtain and thus more expensive. NASA's research on stratified charge rotary engines has demonstrated the capability of these engines to operate efficiently on several different types of fuel, including jet fuel, as well as offering improved efficiency and power relative to current engines.

The primary objective of the Langley Research Center's active noise reduction program is to demonstrate the feasibility of using active noise to cancel out the interior cabin noise generated by the advanced turboprop engines. Using out-of-phase noise, the process has been successfully demonstrated for an idealized system in the laboratory. If successful in

**Lightweight Cabin
Treatment Concept for
Noise Reduction Based on
Helmholtz Resonators**



application, this process would provide substantial weight savings by reducing the amount of acoustic insulating materials currently used on turboprop aircraft while concurrently achieving the internal noise levels typical of today's turbofan aircraft.

One of the Lewis Research Center's projects has been the design and test of a Mach 5 inlet model in their 10 × 10 ft. supersonic wind tunnel. The Center used three dimensional parabolized Navier-Stokes computational techniques. Validation of the calculated results were made



MATERIALS AND STRUCTURES

Advancements in the technical disciplines of materials and structures are necessary to permit the introduction of new civil and military aeronautical vehicles with improved performance, durability, and economy. New materials and structural concepts must be developed that withstand high aerothermal loading cycles in complex airframe configurations that are light weight.

As a result of the evolving materials and structures requirements, NASA has placed increased emphasis on Computational Structural Mechanics (CSM), optimization techniques, active flutter suppression, and advanced high temperature materials research.

Progress has been achieved in the development of enhanced diffusion bonding (EDB) for the fabrication of titanium aluminide honeycomb core sandwich panels. Based on initial metallurgical and mechanical property evaluations of enhanced diffusion bonded joints, the process was scaled up to produce a 6-inch by 6-inch EDB sandwich panel.

EDB has been shown to offer considerable potential for fabricating lightweight, high temperature titanium aluminide sandwich structures. Less than 1% of the weight of these structures can be attributed to the EDB process. In comparison, the weight contribution of braze alloy in a brazen panel would be 20 to 30%

by conducting small scale tests in the one by one ft supersonic wind tunnel. In these validation tests, ramp bleed configurations and shock boundary layer interactions were studied as a means to control boundary layer separation as well as cowl lip and side wall migration. Bleed mechanisms and variable geometry were included in the large-scale model as a result of the advanced analysis and testing in the one by one ft. tunnel.

greater. The process has been developed for the controlled application of EDB material to the edge of honeycomb core material only. As a result, panels as light as 0.5 pounds per square foot have been successfully fabricated.

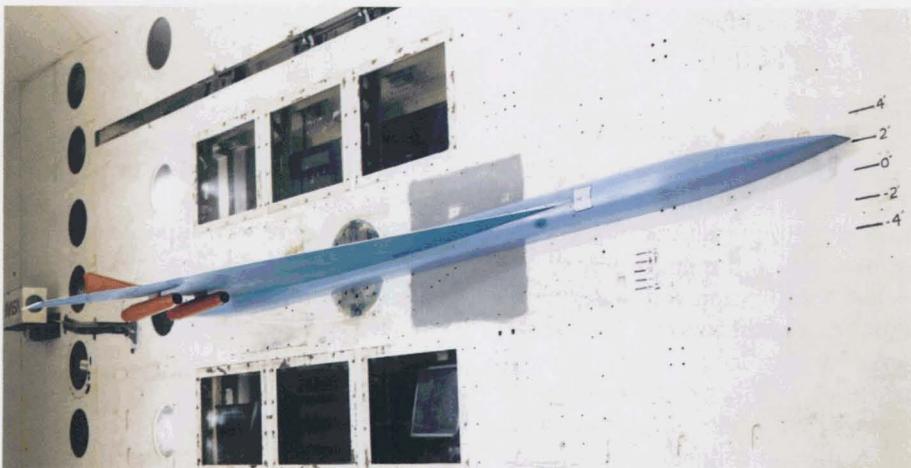
NASA has recently sponsored a program to develop low cost fabrication processes for complex composite airframe structures. The geodesic stiffened spar web developed as a result of this effort, has proven to be a most cost effective and damage tolerant airframe design approach. The objective of this effort was to achieve significant cost reductions in the fabrication of composite structures by utilizing automated filament winding techniques, which reduce costs by 50% compared to conventional hand lay-up methods. Fabrication of composite structures by automated filament winding has also been shown to be 40% cheaper than conventional aluminum fabrication.

Accomplishments to date include the development of a method to filament wind composite spars in pairs using a one-step, fully automated process. Integral supports were wound into the spar webs during fabrication with a major saving in labor cost and time.

With renewed interest in supersonic cruise transport technology and documented flutter deficiencies in previous strength-designed SST's, research on supersonic flutter was initiated in the Langley 16 ft. Transonic Dynamics Tunnel at forward speeds up to Mach 1.2.

The flutter model was a semi-span arrow wing with flow-through engine nacelles and a wing mounted vertical fin. Variables investigated in these tests included the affects of the engine nacelles, vertical fin, wing tip

**Supersonic Flutter Research
in the Transonic Dynamics
Tunnel**



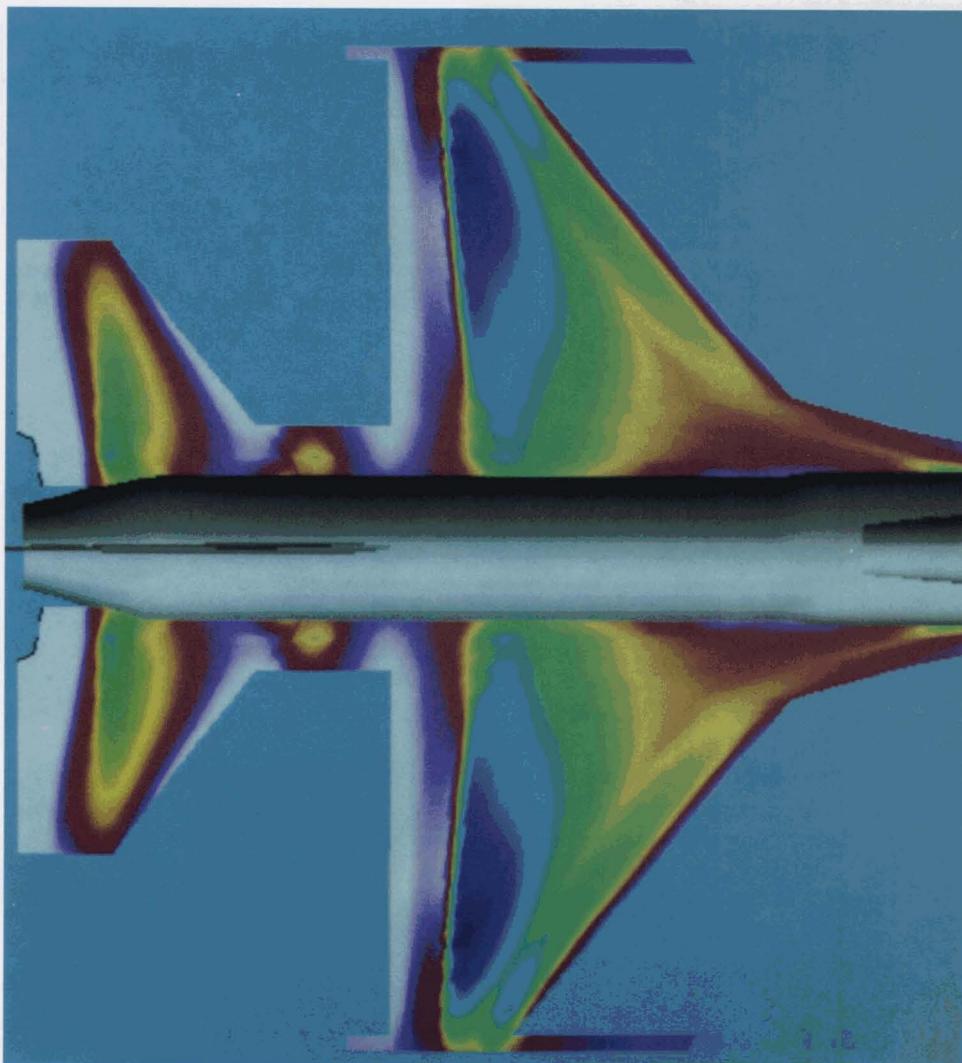
geometry, and angle of attack on the supersonic flutter characteristics of the semi-span arrow wing. In addition, these wind tunnel tests examined the structural relationships between the supersonic flutter problem and the weight of fuel carried in the internal wing fuel tanks. A large data base for this generic SST configuration was compiled for comparison with complementary analytical studies of supersonic cruise flutter characteristics.

Researchers at the Langley Research Center have also developed an advanced capability to computationally predict the unsteady transonic aerodynamic loads on realistic aircraft configurations.

This new procedure is much faster and more stable than previous computational approaches. It achieves this performance by implementing an approximate time-accurate algorithm for solving the unsteady transonic flow equations and efficiently models the entire aircraft, including external stores and weapons, as an assemblage of predefined surfaces and bodies.

The new code can predict both the steady and unsteady pressure distributions over the entire aircraft surface. Shock wave location and strength as well as the aerodynamic interference between bodies can also be predicted. The capability has now been verified by comparison with wind tunnel data.

Superplastic Forming (SPF) is a process which enables the fabrication of uniquely shaped metallic components that would be difficult or impossible to form using conventional methods. SPF, or blow molding, of



aluminum sheet material uses an inert gas to pressurize a tool cavity to form multiple parts in a single operation. This also contributes to reduced fabrication costs. As a result, the application of SPF for fabricating structural components offers a high potential for reducing both the weight and cost of future aerospace structures.

Research has now resulted in the demonstration of compression panels having superplastic formed aluminum stiffeners that are capable of sustaining loads that are 50% higher

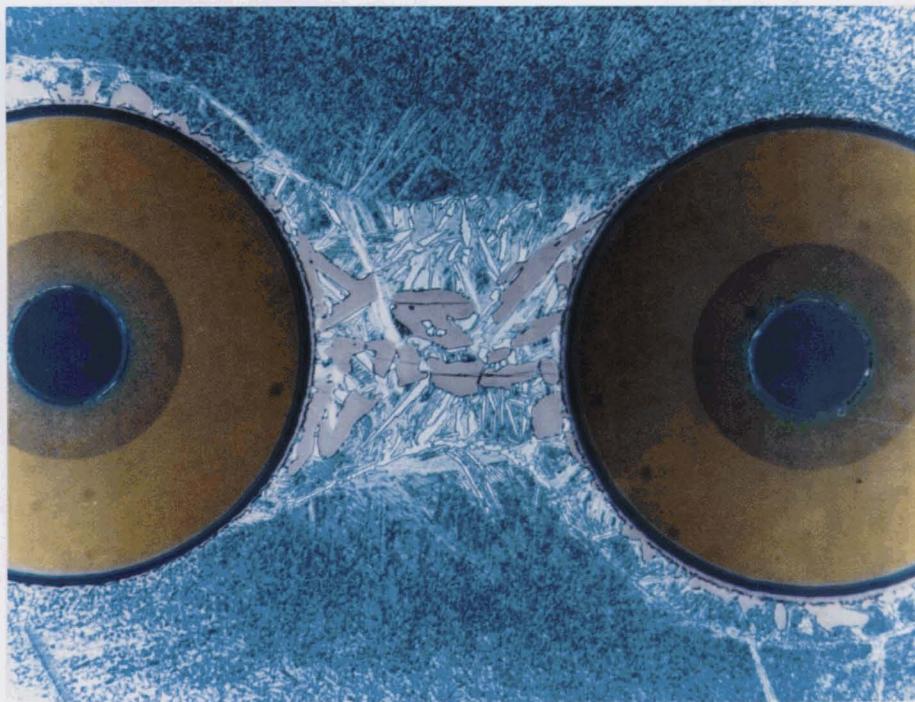
than the load capacity of panels having conventionally formed stiffeners.

Material research engineers have established SPF parameters for both high strength 7XXX series and newly developed aluminum lithium alloys which permit SPF of unusual shapes and configurations desired by the aircraft designer to achieve improved structural efficiency.

The accompanying figure shows a silicon carbide fiber reinforced titanium matrix composite with a complex fiber/matrix structure. The light blue platelets depict chemical reac-

tions and material degradation. The intermetallic matrix composites provide a twofold improvement in strength/density ratio compared to current state-of-the-art high temperature materials.

This research is contributing to the improved understanding of the complex interactions which take place between the fibers and matrix. This will allow the modeling and modification of the composite materials to improve their high temperature properties.



Metal/Intermetallic Matrix Composites

Computer Prediction of
Unsteady Transonic
Aerodynamic Loads

**Simulator Evaluation of
Automated Guidance
Techniques**

INFORMATION SCIENCES AND HUMAN FACTORS

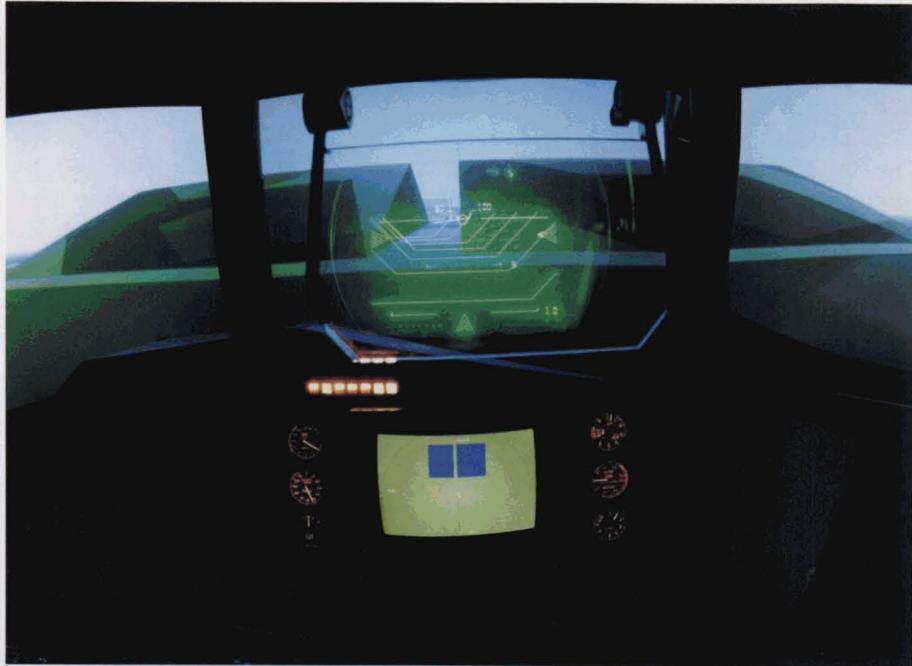
New missions that stretch piloting capability and integrated systems that demand high speed computational processing are the challenges confronting NASA's information sciences and human factors program. The technologies emerging from this rapidly expanding field of science will provide the key to understanding, controlling and optimizing a new family of aeronautical vehicles. Examples include high performance aircraft that can maneuver at ultra high angles-of-attack, transports that can fly more safely in the National Airspace System, and transatmospheric vehicles that can operate routinely across the boundaries of the atmosphere and space.

Controls and Guidance

Controls and guidance research is providing advanced technology to exploit concepts which dramatically improve the operational capabilities of both civil and military aircraft. Major advances in aircraft control



*Advanced Transport
Operating System (ATOPS)
Research Cockpit*

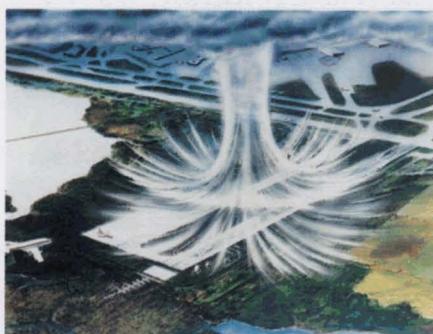


methodologies, reliability and validation techniques, and guidance and display concepts are taking place which will greatly increase the efficiency and effectiveness of the next generation of fixed wing aircraft and rotorcraft.

The return of the Advanced Transport Operating System (ATOPS) B-737 research aircraft to flight status after a modernization upgrade has resulted in a number of successful research projects. An example is the in-flight application of artificial intelligence to flight control system software.

Low altitude wind shear, characterized by rapid changes in wind velocity, has proven to be a great hazard to all aircraft during take-off and landing. Three approaches are being addressed that minimize wind shear hazards. The first, the recently developed F-Factor hazard index which characterizes wind shear potential, has become an industry standard. Second, flight simulation research has demonstrated improved piloting

techniques for recovery from actual wind shear encounters. A third approach involves a computer-aided system that detects dangerous wind shear conditions and provides warning cues to the flight deck. The studies of pilot behavior have helped to establish the viability of such approaches and have provided significant information on how the pilot should respond to a wind shear alert.



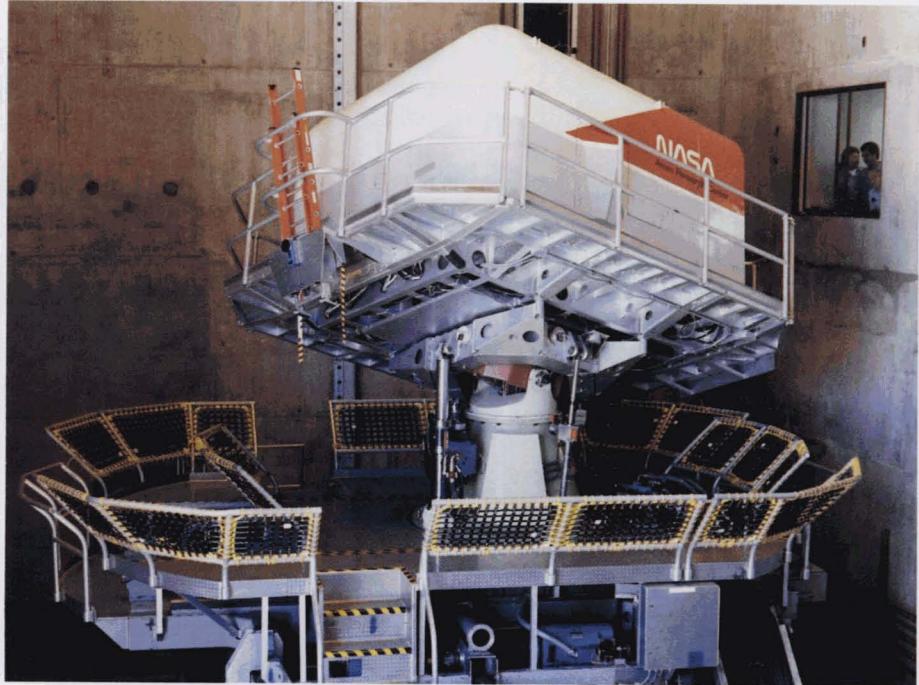
*Artist Concept of Wind
Shear*

**Vertical Motion Simulator
(VMS)**

Concepts for advanced air traffic control and the future integration of 4D-equipped aircraft into the National Airspace System are currently under study to greatly improve the efficiency of air traffic control (ATC) operations. Both simulations and flight tests have been performed by NASA in preparation for a major operational test of these concepts and equipment. The test is to be conducted in conjunction with the FAA at Denver.

A significant milestone was reached with the completion of a research program investigating the character and effect of lightning strikes on aircraft systems. A NASA-developed lightning strike wave-form model has achieved wide acceptance as an industry standard and is now used in the development and evaluation of future aircraft electronic systems.

The Vertical Motion Simulator (VMS) has become fully operational following an upgrade to the rotational motion system. Significantly increased acceleration cues are now possible, allowing for higher fidelity flight simulations. The automated low altitude rotorcraft terrain avoidance system was among the first programs to use the modified VMS. This advanced military mission program is now ready for flight validation. Obstacle detection and avoidance techniques are currently the primary focus of VMS research.



Human Factors

In the past five years, major developments in cockpit automation have occurred with the introduction of more flexible electronic displays and a variety of automated flight management devices. These systems provide fully automated routine flight management from takeoff to landing, regardless of weather, with reduced in-flight workload. The increasing use of cockpit automation can result in certain problems, however, since the air traffic control system has not been upgraded sufficiently to permit the full use of the automated flight control systems.

The recent focus of human factors research has been directed toward pilot interfaces and displays which provide increased margins of safety while drawing extensively upon the

potential value of computer-based and automated system technology. A major program was completed with the field testing of the Traffic Advisory and Collision Avoidance System, which informs a pilot of a potential collision and provides an alternate flight path to avoid the other aircraft. Pilot decisions, responses and consequences were obtained from these tests to verify the adequacy of the system.

Other human factors research involving the uses of flight automation was demonstrated by the Army/NASA Aircrew Aircraft Integration program. A designer's workbench

Cockpit Simulation in Man-Vehicle Systems Research Facility (MVSRF)



was developed which allows an aircraft designer to select different helicopter missions, performance profiles and cockpit arrangements, and combine these options with several different human physical and mental performance models, to determine which combination of factors constitute the optimum system.

In another area of helicopter research, NASA identified sources of pilot error in Emergency Medical Services helicopter operations. The National Transportation Safety Board had requested analysis of these operations because of their unusually high accident rate.

Computer Science

Significant accomplishments in computer science are providing the technology necessary to aggressively and effectively realize the tremendous potential of advanced computer architectures for solutions to large-scale scientific problems. Fundamental studies of new architectures and the algorithms to exploit the full power of these computers are being conducted at the Research Institute for Advanced Computer Science established at the Ames Research Center. The results of this research are making significant contributions to advance the state-of-the-art in computational fluid dynamics, computational chemistry and other disciplines.

Very large scale integrated (VLSI) circuit technology has made the computer architect's design task very demanding, requiring many design tradeoffs. The Architect's Workbench developed by Stanford University under a NASA grant provides very efficient simulation of processor and memory options allowing immediate design analysis instead of several weeks of effort previously required per prototype iteration.

A NASA challenge is to develop machines and systems that are capable of learning to perform tasks in places that are either too remote and too hostile or too tedious for humans. The Sparse Distributed Memory project is investigating the theory and applications of a massively parallel computing architecture that will support the storage and retrieval of sensor and motor patterns required by autonomous systems.

Ray tracing is the current method for the state-of-the-art production of realistic computer generated imagery. Computer processing speed is currently inadequate for making quickly produced ray tracing images practical. Efforts in this area are directed at developing a ray tracing processor which would break this speed barrier. This would mean a new frontier for graphics applications in a wide range of scientific disciplines.

Software tolerance and software fault elimination are two techniques for improving software reliability and both have been used for critical applications such as the control of aircraft, railroads, and nuclear power plants. There is, however a growing tendency to reduce software testing or to rely solely on multi-version software testing to reduce software development costs. Recent research is now providing the first empirical data comparing fault elimination and fault tolerance methods. The initial results of this research suggest that the trends of reduced software testing may be improper for critical applications.

The upcoming High Performance Computing Initiative program will accelerate the development and application of high-performance computing technologies to meet science and engineering requirements for continued U. S. leadership.

F-111 Mission Adaptive Wing (MAW) Flight Tests

FLIGHT SYSTEMS/ SAFETY

In each discipline area such as aerodynamics, structures, flight controls and propulsion there exists a need to validate the research through actual flight testing of new components and systems. In some instances, aeronautical research can only be performed or validated in flight. This in-flight validation is frequently accomplished by using high performance aircraft as test platforms. These aircraft are often provided by agencies of the Department of Defense under long standing agreements with NASA in connection with one element of the NASA charter, which is to support the development of military aviation technology. NASA utilizes these aircraft primarily in flight research programs conducted at the Ames Research Center-Dryden Flight Research Facility.

Flight Systems

The objective of the recently completed Mission Adaptive Wing (MAW) program was to demonstrate and evaluate predicted aerodynamic performance improvements by incorporating variable-camber in a supercritical wing design. By investigating selected areas of the flight envelope of the F-111 test aircraft, a data base has been developed that can be used to apply this technology to both future civilian and military aircraft. Areas investigated included performance, handling qualities, air loads, buffet, and wing pressure distributions. Testing of four automatic flight control modes and a manual flight control system was also accomplished.



In addition to establishing a technical data base, a number of specific results have been achieved: drag was reduced 8% at the design lift coefficient of 0.42; the drag was reduced by 20% at the off-design lift coefficient of 0.80; the buffet onset boundary was increased 30%; and wing bending in maneuvering flight was reduced by 20%.

The flight results have shown that the performance of a variable-camber wing is much better than predicted and significantly improved over a fixed-camber wing.

The F-106 aircraft was successfully flown with a leading edge vortex flap installed. Initial flights investigated low speed handling qualities, stability and control, structural dynamics, and maneuver loads.

In this program, small cones, which align themselves with the flow, were attached to the vortex flap and wing. On-board video cameras

were used to observe and record motions of the vortex system in flight for correlation with data from over 60 strain gages and 296 pressure ports distributed along the wings.

This flight research program is providing data to validate a potential 30% improvement in the lift/drag ratio with attendant improvements in stability, control, and maneuverability. The vortex flap was developed following extensive wind tunnel tests, which were complemented by analytical studies using both new and existing CFD codes. The flight test data is currently being correlated with both the CFD and wind tunnel results. In order to establish an initial baseline for comparison, sixteen flights of the fully instrumented aircraft were performed without the vortex flaps installed.

The overall objectives of the Highly Integrated Digital Electronic Control (HIDEC) program are to develop, demonstrate, and evaluate the potential improvements in aircraft performance and mission effectiveness made possible by proper integration of the engine, inlet, and airframe systems.

**Highly Integrated Digital
Electronic Control (HIDEC)
F-15 Flight Research
Aircraft**



The HIDEC program evolved from earlier accomplishments in the Digital Electronic Engine Control program, the F-100 Engine Model Derivative program, and previous YF-12/SR-71 programs as part of NASA's long involvement in integrated controls research.

The test aircraft used in the HIDEC program was a pre-production F-15A on loan to NASA from the Air Force. The aircraft was aerodynamically equivalent to production versions of the F-15, but incorporated extensive modifications to the aircraft and engine electronic control systems.

The Adaptive Engine Control System (ADECS) was flight tested as a part of the overall HIDEC effort. The objectives of the ADECS portion of the HIDEC program are to develop, demonstrate, and evaluate the integration of the engine and airframe controls.

Significant performance improvements were realized with the ADECS engaged, compared to the baseline performance of the aircraft with the ADECS disengaged. For example, there was a 24% decrease in elapsed time to accelerate from Mach 0.8 to 1.5 at an altitude of 50,000 ft.

Thrust improvements of up to 10% were realized throughout a large portion of the flight envelope. Other results demonstrated reductions in specific fuel consumption ranging from 11 to 16 percent at maximum power.

Based on the results of the HIDEC program, it has been demonstrated that the ADECS offers the potential to upgrade the performance of existing aircraft without the need to install new engines. Furthermore, new tactical aircraft are likely to be equipped with everything required to implement an ADECS system, i.e., digital flight and engine control systems, inertial navigation, and digital data buses. Therefore, the performance advantages of integrated flight and propulsion control will be easily achievable at little additional cost.

Flight Safety

An important aspect of NASA's aeronautical research and technology program is the investigation of atmospheric phenomena critical to the operational safety of both civil and military aircraft. Research is focused on the understanding and prediction of natural environmental factors that have an impact on the operational safety of aircraft. Areas of special concern include: storm hazards, lightning, gusts, turbulence, rain effects, icing and wind shear. In accordance with NASA's charter, the safety related research is conducted in support of, and in close coordination with, the FAA, which has the primary responsibility for aircraft safety.

Improving flight safety through research in natural operating environments is viewed as vital by NASA. The research is being addressed from the perspective of understanding the

natural phenomena, as well as developing flight systems responsive to the hazards these environments present.

The Storm Hazards Program includes research on lightning and heavy rain effects. Heavy rain can momentarily alter airfoil shapes, which can temporarily degrade aircraft performance. Wind tunnel results have shown significant aerodynamic performance degradation in simulated heavy rain, however, verification and development of scaling relationships for extrapolating the wind tunnel results to actual flight systems requires additional data on full-scale effects. In order to meet this requirement, large-scale tests have been initiated which utilize the modified Aircraft Landing Dynamics Facility (ALDF) at the Langley Research Center.

A full scale wing mounted on the ALDF carriage is propelled at speeds of 100 to 170 knots and at angles-of-attack ranging from 6 to 20 degrees. The wing passes through simulated rain falling at rates of 2 to 40 inches per hour. Measurements of the wing lift and drag are being taken to provide the large-scale test data necessary for assessing the effects of rain on the aerodynamic performance of full-scale systems.

NASA icing research is aimed at understanding the physics of ice accretion on aircraft surfaces, and the affects of ice formation on the aircraft's performance and handling qualities. In addition, this research is exploring means of preventing ice accretion, and methods of deicing the aircraft once ice does form. Analytical and experimental methods have been developed to determine the changes in aircraft performance and handling qualities. In the past,

Heavy Rain Effects
*Investigation in the Aircraft
 Landing Dynamics Facility
 (ALDF)*



little or no quantitative icing data existed that was useful for the complex engineering analyses which are required to determine these icing effects.

The new analytical and experimental results are incorporated in the 'LEWICE' icing prediction code which includes advanced ice accretion, aero-performance, heat transfer, and thermal deicer sub-codes. In addition, icing methodology for rotors and propellers is being developed, as well as methodology for simulating the aircraft response to an icing encounter.

In the area of ice protection, evaluation of advanced concepts is continuing and includes the electro-expulsive deicer system. This system uses electromagnetic pulses which are transmitted through wires embedded in a flexible aircraft surface covering. These electrical impulses impart mechanical motions in the surface to eject ice built up on that surface.

Several flight tests were conducted in cooperation with the Army to accelerate development of instrumentation for cloud characterization and to

improve the Army's Helicopter Icing Spray System (HISS) which is used to create in-flight icing conditions through which helicopters can be flown and evaluated.

The first recalibration of the Icing Research Tunnel (IRT) since 1956 was recently completed and a helicopter rotor was tested in the IRT for the first time. This rotor test, which employed an OH-58 tail rotor, was the first step in the development of a new test capability for rotorcraft icing.

Flight Test Instrumentation

The objectives of the flight test instrumentation activity are to significantly improve the efficiency of flight testing, increase the accuracy of information (data) obtained in flight, and develop techniques for acquiring necessary information previously unobtainable in flight.

Existing prototype or production aircraft are normally used as test

platforms for evaluating new flight test techniques and instrumentation. This results in the rapid implementation, analysis and assessment of new testing methods. Flight testing is the only way of simultaneously duplicating specific combinations of variables such as temperature, pressure, density, viscosity, and Reynolds number representative of real atmospheric flight conditions.

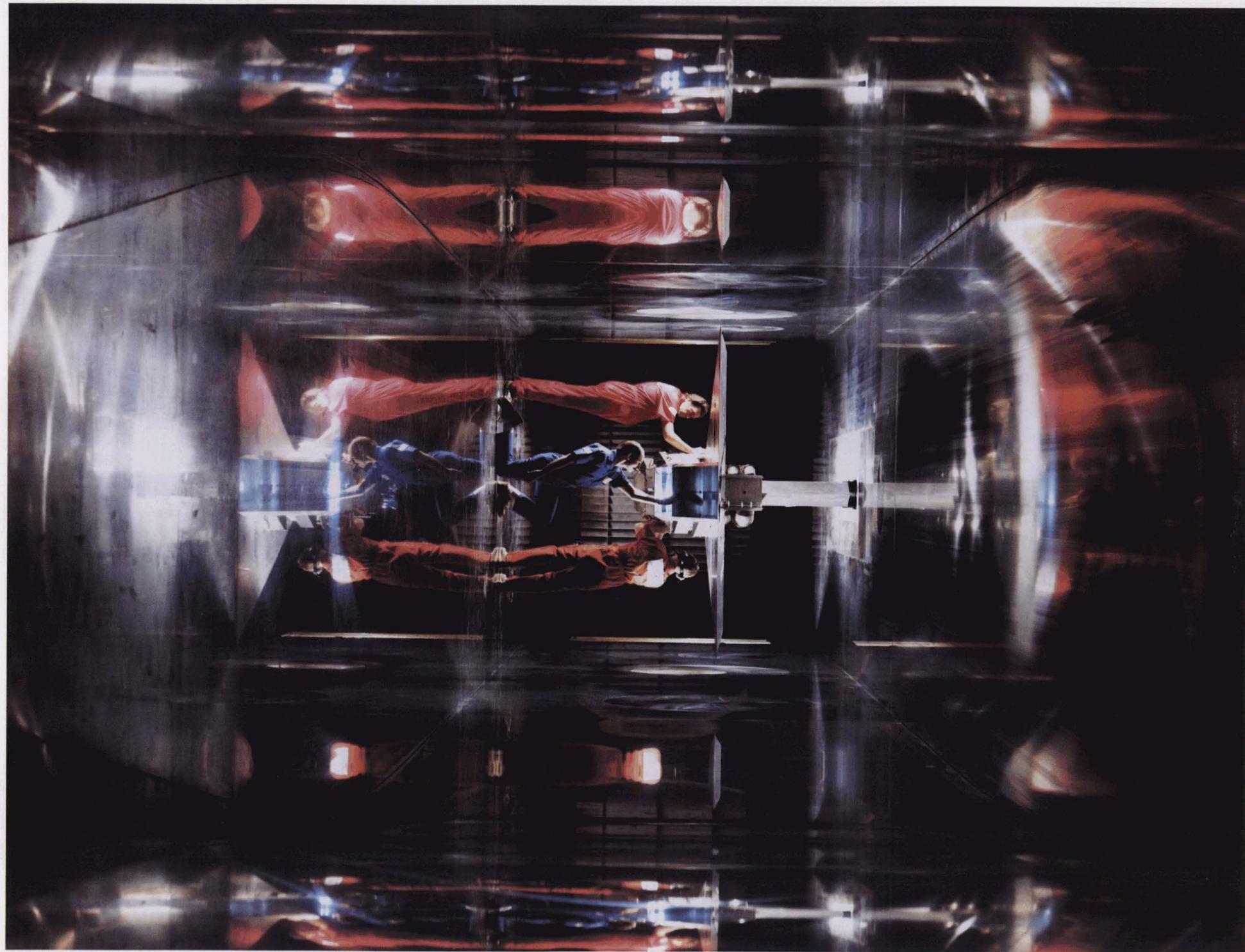
A series of flight tests are being conducted with an F-104 aircraft to determine the feasibility of using manned aircraft instead of weather balloons to obtain more timely data on winds aloft prior to shuttle launches. The identification of wind shears that might produce high aerodynamic loads on the shuttle during launch are of particular concern.

The F-104 test bed, which is being flown at Ames-Dryden, was chosen for the wind monitoring study because of its ability to make high speed climbs to 60,000 feet. The aircraft is equipped with inertial navigation (INS), telemetry, and test instrumentation systems, and a nose boom has been installed for sensing true airspeed and freestream angle of attack.

All test flights are tracked by radar, providing a backup source of ground speed data to compare with INS derived wind speed information.



F-104 Aircraft with Flight Test Fixture Installed



ORGANIZATION AND INSTALLATIONS

AERONAUTICS ORGANIZATION

The NASA Aeronautics Research and Technology program is carried out under the direction of the Associate Administrator for Aeronautics and Space Technology. The Office of Aeronautics and Space Technology (OAST) is responsible for the planning, advocacy, direction, execution and evaluation of projects and research activities concerned with aeronautics and space technology, in addition to providing line institutional management of the Ames, Langley and Lewis Research Centers.

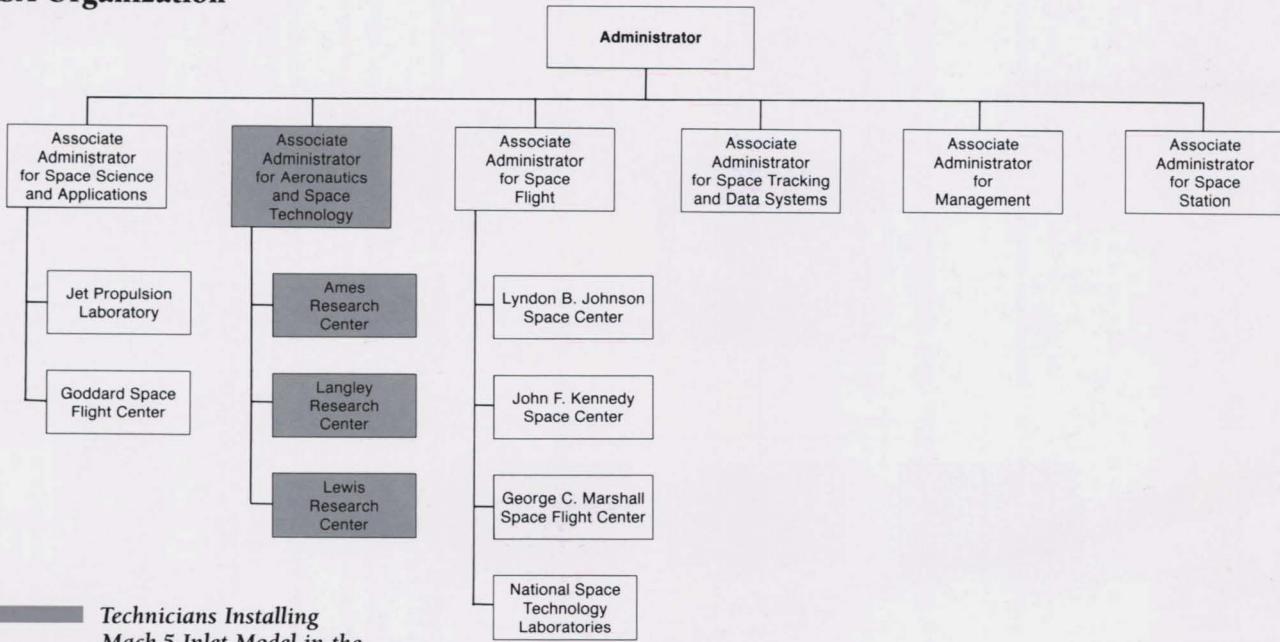
Within OAST, the Director for Aeronautics has overall responsibility for the aeronautics programs. This includes strategy, planning, advocacy, direction, execution and evaluation of the overall program. In addition, the Director for Aeronautics is the principal OAST external interface

on aeronautics with Congress, advisory committees, industry, universities, DoD, FAA, and other government agencies. He discharges these duties through close coordination and interaction with the OAST Discipline Divisions and with other program and institutional directors. For example, there is ongoing interaction with the Director for Space on synergistic research activities that have application to both Aeronautics and Space, and with the Director for Institutions on Research Center institutional planning, budgeting, management, advocacy of facilities, and automated data processing equipment. The Division Directors in support of the Director for Aeronautics, establish discipline program plans and objectives, and determine facility requirements consistent with overall program strategy and long range directions. The Discipline Divisions have primary responsibility for implementation of the research programs and flight projects through the Research Centers and for reporting

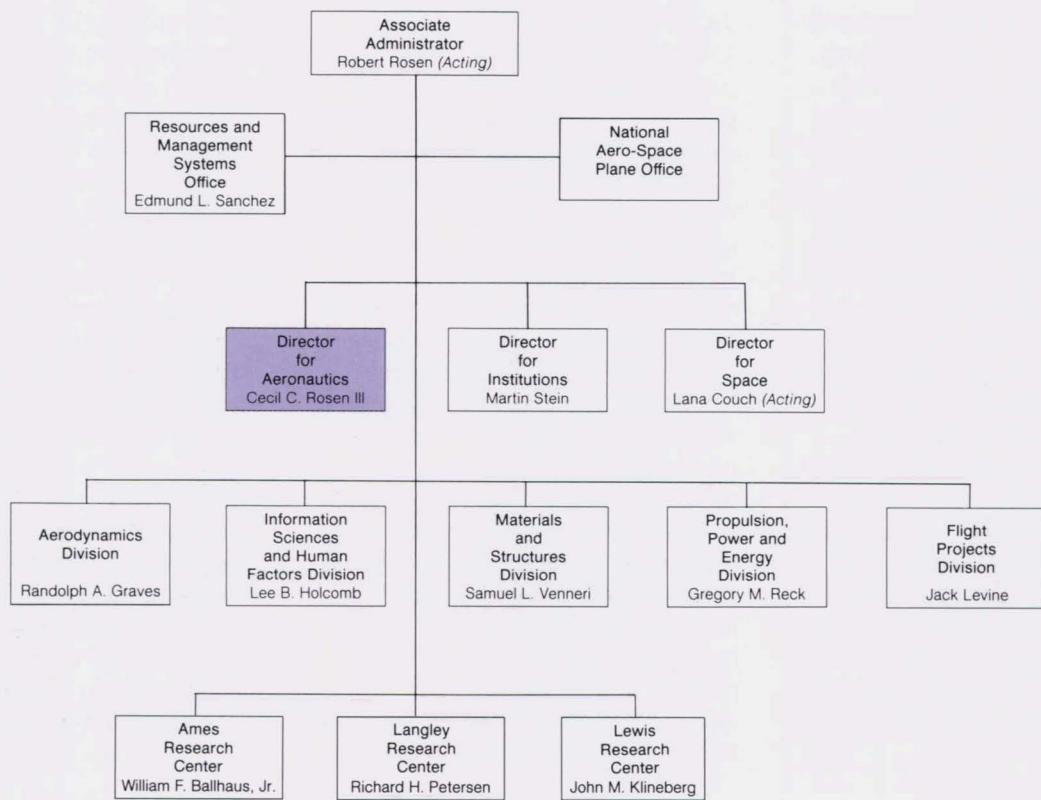
and evaluating progress relative to plan. The Research Centers implement and manage the ongoing aeronautics programs, and participate jointly with OAST in developing strategic plans and in establishing future research and facility requirements.

The Director for Aeronautics is supported by a Deputy Director and by three Assistant Directors for the specific vehicle classes of General Aviation and Transport Aircraft, Rotorcraft, and High-Performance Aircraft. The Deputy Director, in addition to supporting the overall direction of the aeronautics program, focuses specific attention on broad strategy and policy issues. For each vehicle class, the respective Assistant Director defines R&T requirements based on user needs and evolving opportunities, ensures the proper balance of vehicle related research, develops vehicle long range program roadmaps, and is the principal OAST external interface with industry, DoD, and other government agencies.

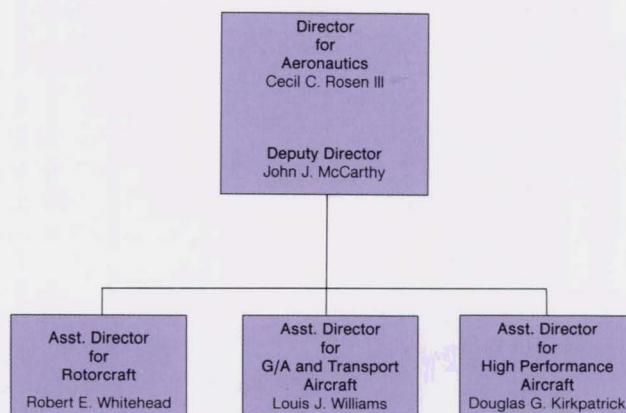
NASA Organization



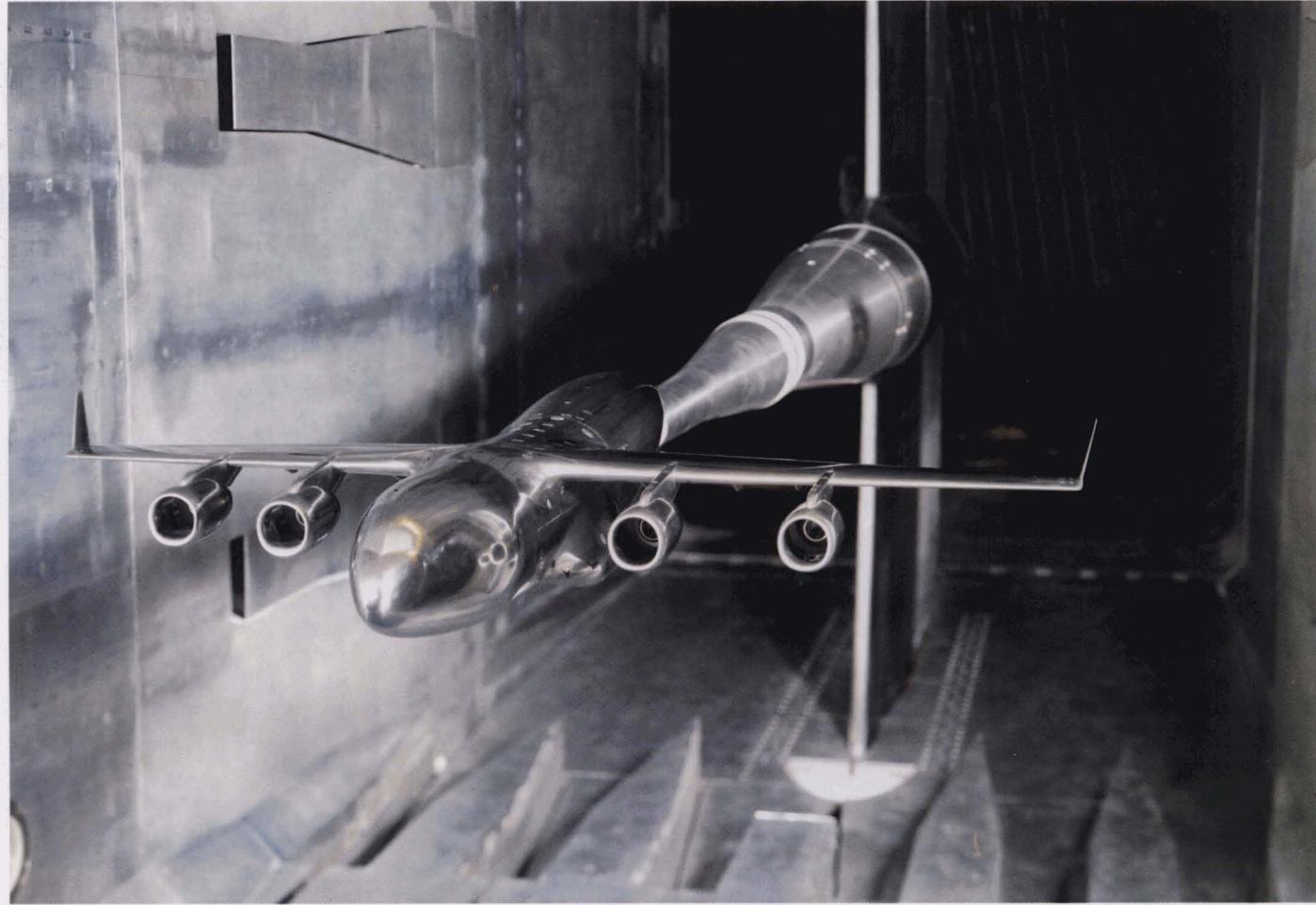
Office of Aeronautics and Space Technology



Aeronautics Directorate



**High Wing Transport Model
in National Transonic
Facility**



WIND TUNNEL REVITALIZATION

In its aeronautical R&T programs, NASA utilizes a unique complement of wind tunnels which have supported the nation's civil and military aircraft developments for many years and which are valued at several billions of dollars. The average age of the wind tunnels is more than 30 years.

In 1987, NASA established a team of independent experts to conduct a critical assessment of the physical condition and productivity of the wind tunnels and projected demands

for their use. The assessment indicated a serious need for modernization or refurbishment of many of the tunnels and their instrumentation, support equipment, and data systems. These findings were confirmed in separate reviews by NASA's Aeronautics Advisory Committee and the National Research Council's Aeronautics and Space Engineering Board.

In response to these assessments, NASA, in 1989, initiated a major wind tunnel revitalization program to be completed in 1993 at an esti-

mated cost of more than \$250 million. The 1989 activity has included design work on three of the most urgent projects: replacement of the structural shell and refurbishment of the test section and equipment for the Ames 12 ft. pressure wind tunnel; rehabilitation of motors and critical equipment for the Lewis 10 by 10 ft. supersonic tunnel, and modernization of nozzles, heaters and controls for the hypersonic facilities complex at Langley. Construction on the Lewis tunnel and the Langley facilities are scheduled to begin in March, 1989; construction on the Ames tunnel is scheduled to begin December, 1989.

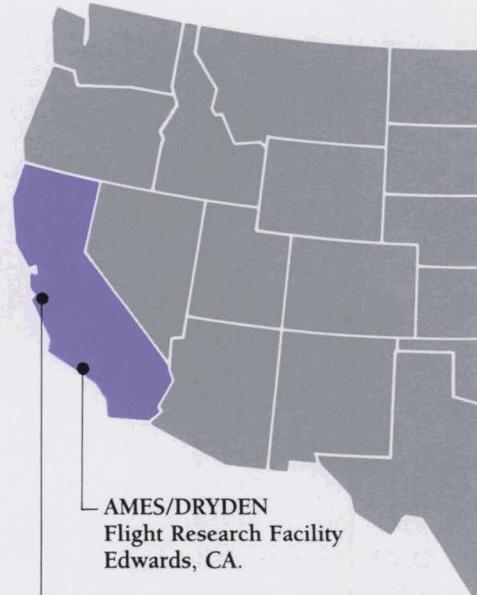
NASA RESEARCH CENTERS

The NASA Aeronautics Research and Technology program is conducted at NASA research centers located in California, Ohio, and Virginia. The accompanying map shows the locations of each aeronautical research center together with a listing of the Center Director and key aeronautical managers. Each center has unique facilities and research staff expertise that provide a significant national resource for the pursuit of new advancements in aeronautical technology. Each center conducts extensive in-house research utilizing special facilities and equipment. In addition, each center conducts research in close coordination with other government research organizations, universities and industry. The university research is supported through various grant programs and the industry research is carried out through numerous cooperative research projects and through direct contracted research with industry and private research organizations.



Ames Research Center (ARC)

The Ames Research Center areas of aeronautical excellence include staff expertise and unique facility capabilities in computational fluid dynamics and computer science applications which focus on the development of new analytical methods using the growing power of advanced computers. The Center has unique facilities in aerodynamic testing and flight simulation for the purpose of validating the analytical methods and conducting research investigations of both small and large scale aeronautical vehicle configurations. In addition, the Center conducts human factors, aircraft automation, flight dynamics, guidance and digital controls research.



AMES/DRYDEN
Flight Research Facility
Edwards, CA.

AMES
Research Center
Moffett Field, CA

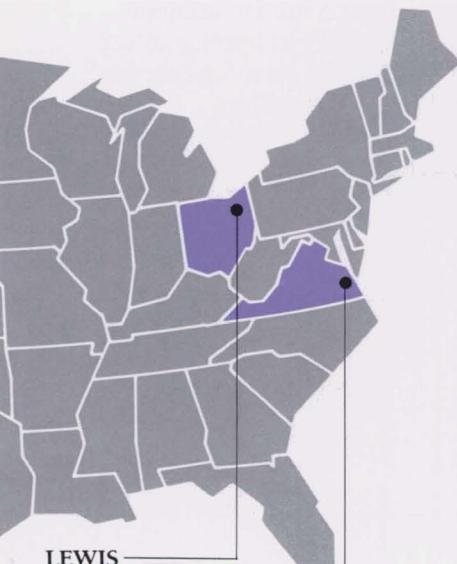
W.F. Ballhaus, Jr.
V.L. Peterson
C.T. Snyder
M.A. Knutson



Ames/Dryden Flight Research Facility (DFRF)

The extensive flight test research capability of the Dryden Facility complements Ames' ground test capability. Key systems technology areas at the two Centers include:

- ▼ Propulsion/Airframe Integration.
- ▼ Powered Lift Technology.
- ▼ Rotorcraft Aeromechanics.



LEWIS
Research Center
Cleveland, OH

J.M. Klineberg
N.T. Saunders
J.S. Fordyce

LANGLEY
Research Center
Hampton, VA

R.H. Petersen
R.V. Harris, Jr.
J.F. Creedon
C.P. Blankenship



Lewis Research Center (LeRC)

The Lewis Research Center features aeronautical excellence in propulsion. The Center's research and technology expertise has been divided into four main thrusts for strategic planning purposes: aeropropulsion, space propulsion, space power, and space science/applications. There are, in addition, other research activities at the Center in various basic and applied technical disciplines that support these main thrusts and are critical to meeting national needs and NASA objectives.

The aeropropulsion strategic objectives are to advance and strengthen aeropropulsion technology that will contribute significantly to the development of U. S. civil and military aircraft. Five supporting research disciplines have been identified as critical to future aeropropulsion R&T efforts and are currently being pursued: materials, structural mechanics, internal fluid mechanics, instrumentation and controls, and electronics.



Langley Research Center (LaRC)

The Langley Research Center areas of aeronautical excellence include staff expertise and unique facility capabilities in fundamental aerodynamics and fluid dynamics, computer science, unsteady aerodynamics and aeroelasticity. Aerodynamic testing to support the research in each of these areas is a major focus of the Center. In addition, the Center is a leader in structures and materials research with a primary focus on the development and validation of structural analysis methods and research in airframe metallic and composite materials. The Center also conducts fundamental research on fault tolerant electronic systems and flight control. Special areas of research include:

- ▼ Simulation and Evaluation of Advanced Operational Aircraft Systems.
- ▼ Acoustics and Noise Reduction.
- ▼ Propulsion/Airframe Integration.

SUPPORTIVE RESOURCES

UNIVERSITY PROGRAMS

The NASA Aeronautics Program devotes approximately ten percent of its Research and Development resources to support the Nation's Universities in conducting long range, high-risk research and design studies; developing innovative, creative approaches to concept development; and enhancing existing university technological curriculum through close coordination between Universities and NASA Research Centers. The major portion is for Basic Research Grants which are used by university researchers to extend mainstream aeronautical basic research. NASA Research Centers provide support through the Fund for Independent Research which supports innovative, high-risk research conducted at universities. This research is focused on long term objectives and extending basic technologies.

The **Research Institutes** located at the Research Centers are for strengthening specific capabilities within the program by bringing in leading university researchers on a temporary basis to work with NASA personnel on specific applications and to utilize the unique facilities at the centers.

Research Center	Institute
Ames Research Center	Research Institute for Advanced Computer Science
Langley Research Center	Institute for Computer Applications in Science and Engineering
Lewis Research Center	Institute for Computational Mechanics in Propulsion

Centers of Excellence have been established at specific universities to develop a unique expertise and to accelerate progress in new/emerging fields. At the university there is a "critical mass" of key faculty established to conduct research, to train students, and to foster interdisciplinary interactions between the universities, the Research Centers, DoD, and industry.

Discipline	University
Ceramics	University of Michigan
Computer Science	University of Illinois
Computer Science	Stanford University
Material Science	Virginia Polytechnic Institute and State University
High-Temperature Material	Pennsylvania State University
Innovative Material Processing Science	University of Virginia

The **Joint Institutes** established at the Research Center are to promote an active NASA/university interchange in the mainstream cooperative, innovative research areas.

Research Center	Joint Institute
Ames Research Center	Joint Institute for Aeronautics and Acoustics
Dryden Flight Research Facility	Joint Institute for Flight Research
Langley Research Center	Joint Institute for Advancement of Flight Science
Lewis Research Center	Joint Institute for Aeronautical Propulsion and Power

NASA initiated a pilot undergraduate program with six universities in Aeronautical Systems Design Studies to develop an understanding of and appreciation for systems design/analysis at the universities, surface new innovative ideas that have potential payoff and promote enthusiasm in students and professors for aeronautical systems.

Research Center	Joint Institute
Ames Research Center	California Polytechnic State University, San Luis Obispo
Dryden Flight Research Facility	California State Polytechnic University, Pomona
Langley Research Center	University of California, Los Angeles

Case Western Reserve University
Ohio State University
University of Kansas
Purdue University

Since the National Aero-Space Plane is evolving as a vehicle for the future, and due to the increased interest in hypersonic flight, NASA established **Training Grants in Hypersonics** with six universities. These grants are to develop a graduate level curriculum and to conduct basic research in hypersonics. This was accomplished with help from the Navy and the Air Force.

Universities
Stanford University
State University of New York
University of Texas at Austin
Ohio State University
University of Southern California
North Carolina State University

The **Graduate Program in Aeronautics** sponsors research that is relevant to both NASA and universities, encouraging new graduates to pursue advanced degrees in aeronautics. The program involves over 100 students at about 50 institutions.

The **NASA/National Research Council Resident Research Associateship Program** sponsors post-doctoral scientists and engineers of unusual promise and ability to perform research at the centers for one year with consideration for a one year extension.

The **American Society for Engineering Education Summer Faculty Fellowship Program** provides the opportunity for university professors to do research at NASA's centers during the summer for the purpose of furthering the knowledge of the science faculty, stimulating the exchange of ideas between NASA and university personnel, enriching the research and training activities of the participants' institution, and contributing to NASA's research objectives.

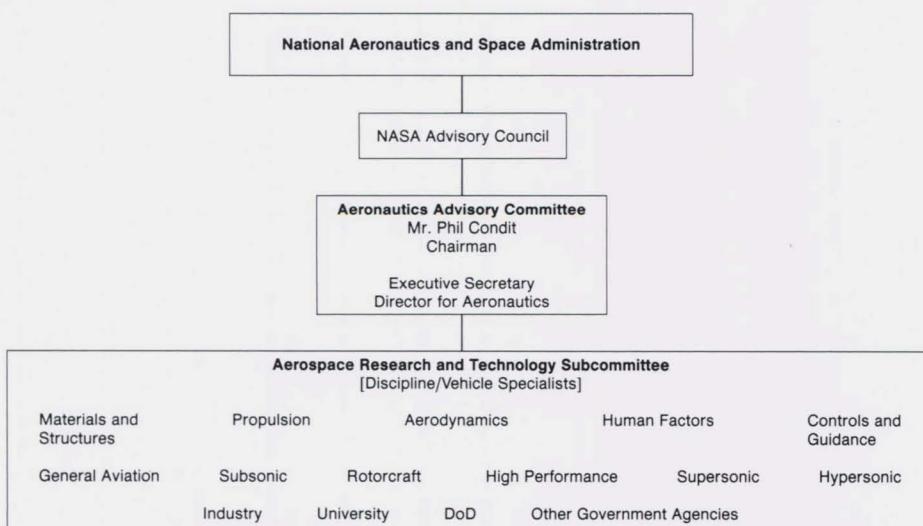
The **NASA Graduate Students Research Program** has the objective of increasing the number of highly-trained aerospace scientists and engineers and sponsoring thesis/dissertation research in areas of interest to NASA.

AERONAUTICS ADVISORY COMMITTEE

NASA receives valuable guidance and technical advice regarding aeronautics research and technology programs from external sources such as the Aeronautics Advisory Committee (AAC) of the NASA Advisory Council, a primary mechanism for interacting with the external technical community of aeronautics experts. The AAC makes recommendations based upon periodic reviews of NASA's technical plans, research priorities and program progress. This advisory function provides NASA with critical guidance in planning, coordinating, and assessing the aeronautics program, and expeditiously transferring technology to the nation's aerospace industry.

The AAC consists of 15 to 20 members from industry, academia and government selected for their expertise in specific technical areas of aeronautics. Supporting the AAC is a larger group of discipline and vehicle specialists who make up the Aerospace Research and Technology Subcommittee (ARTS). The AAC defines specific topics of interest or concern that require in-depth review. Technical specialists from the ARTS are selected, based on their expertise in the topical area, to conduct a detailed assessment and to develop recommendations for AAC consideration.

Given the rapidly changing nature of aeronautics, the role of the AAC is critical to maintaining an aggressive and productive aeronautics research and technology program. The continuous dialogue between OAST and the AAC assists NASA in prioritizing research efforts to meet the nation's aeronautical technology needs.





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